Request for Mars Scout Concepts

for

Mars Scouts Studies

Date: March 15, 2001

TABLE OF CONTENTS

SUBJECT: Mars Scout Mission Request for Concept Study Abstracts

The objective of this letter is to solicit abstracts from candidates to identify, evaluate and select concepts for additional study.

The NASA Mars Exploration Program is planning a series of Principal Investigator led, innovative science missions that emerge from the U.S. Science Community. The first launch of such a mission could be as early as 2007. Mars Scouts Missions address high priority science as defined by the Mars Exploration Payload Analysis Group document located a http://spacesciences.nasa.gov/an/marsscoutsworkshop/. They may also address new discoveries, particularly those discoveries that warrant rapid follow-up. NASA intends to use Mars Scouts to complement the core Mars Exploration Program of scientific missions.

The Mars Exploration Program now seeks to encourage the development of new concepts for Mars Scout Missions. Through the study of specific mission concepts, the Mars Exploration Program also seeks to understand the feasibility of a variety of mission types before the program releases a call for proposals for a flight opportunity as early as 2007.

Exploration of Mars is motivated by a desire to better understand the planet as a possible abode of past or present life, the evolution of the planet's climate, the geology of its surface an interior, and to prepare for future human exploration of Mars. Mars Scout missions are envisioned to be focused investigations of Martian biological, chemical and physical phenomena and processes. Mars Scouts will utilize observation platforms including, but not limited to, orbiters, landers, penetrators, rovers, aerobots, airplanes and gliders.

This request is for a six (6) month effort to examine a wide range of mission concepts that, if flown to Mars, would cost approximately $300M (FY '01 Dollars), would accomplish significant, high priority science, and complement the goals of the core missions of the Mars Exploration Program. Studies of mission concepts will identify achievable science objectives and technology development priorities. Mars Scouts technology development is supportable via the ongoing Mars Technology Program. It is planned to award fixed-price study contracts valued at $100,000 to $150,000 each. Potential participants are encouraged to for teams including academic, industrial and U.S. Government Research Centers.

The following provides general instructions and information regarding preparation of your Concept in response to this letter. The effort to be performed, performance period and contract type will be in accordance with the Specimen contract in Exhibit IX.

The contract will be awarded via a competitive source evaluation and source selection process, and will include written and oral presentations to an evaluation board at the Mars Scout Workshop scheduled for May 22 - 24, 2001. Participation in the Mars Scout Workshop will be limited to those interested in proposing for study funds. Notice of intent to propose are required by April 9. Then, a maximum seven-page abstract describing the Mars Scout concept and a plan for the mission study is due by May 1. It is the intent of the workshop, and the following funded mission studies, to emphasize those innovative concepts that may not yet be ready for competitive evaluation. Potential participants will be informed of their status regarding study funds no later than June 08, 2001.

Following the 6-month period of study a report on the results of each funded study will be made by the investigator, in confidence, to the Mars Program Director's Office at NASA HQ. Participation or non-participation in Mars Scout studies will not prejudice the subsequent selection of missions for flight.

All questions related to this procurement shall be directed to jparrish@mail.hq.nasa.gov.

Mars Program General Description

The Mars Exploration Program is a science-driven, technology-enabled effort to characterize and understand Mars, including its current environment, climate and geological history, and biological potential.

The Mars Exploration Program encompasses all NASA Mars robotic mission activities and analysis undertaken to characterize the solid planet and it's atmosphere, it's geological history, it's climate and the relationship to Earth's climate change process, to determine what resources it provides for future exploration, and to search for evidence of extinct or extant life on Mars. The Mars Exploration Program missions will also support data collection and technology demonstrations critical to planning and carrying out future human missions to Mars.

The Mars Exploration Program has established the following science goals:

- Goal - Life: Determine whether life ever arose on Mars
  - Determine if life exists today
  - Determine if life existed on Mars in the past
  - Assess the extent of prebiotic organic chemical evolution on Mars
- Goal - Climate
  - Characterize Mars' present climate and climate processes
  - Characterize Mars' ancient climate
- Goal - Geology
  - Determine the geological process that have resulted in formation of the Martian crust and surface
  - Characterize the structure, dynamics, and history of the planet's interior
- Goal - Prepare for human exploration
  - Acquire appropriate Martian environmental data such as radiation
  - Conduct in-situ engineering and science demonstrations
  - Emplace infrastructure for future missions

The currently envisioned future mission set is described in more detail below. Mars Scouts complement the future mission set.

Mars Odyssey 2001

Mission Description

- Launch - April 2001/Mars Orbit Insertion - October 2001
- Prime Mission - 76 days aerobraking, science mission through Dec. 2003, relay mission through Oct. 2005
- Science Payload
  - Thermal Emission Imaging System (THEMIS)
  - Gamma Ray Spectrometer (GRS)
  - Mars Radiation Environment Experiment (MARIE)

Primary Objectives

- THEMIS will map the mineralogy and morphology of the Martian surface using a high-resolution camera and a thermal infrared imaging spectrometer
- GRS will achieve global mapping of the elemental composition of the surface and determine the abundance of hydrogen in the shallow subsurface. GRS is a clone of the instrument lost with the Mars Observer mission.
- MARIE will describe aspects of the near-space radiation environment, especially the radiation risk to human explorers.
- Provide communications link for future Mars missions

2003 Twin Mars Exploration Rovers

Mission Description

- Launch - May/June 2003 / Mars Landing - January 2004
- Prime Mission - 90 days surface operations, until late April 2004; could be continue longer depending on health of the rovers.
- "Athena" Science payload -
  - Panoramic Camera (Pancam)
  - Miniature Thermal Emission Spectrometer (Mini-TES)
  - Mössbauer Spectrometer
  - Alpha-Proton X-ray Spectrometer
  - Rock Abrasion Tool
  - Microscopic Imager

Primary Objectives:

- Determine the aqueous, climatic, and geologic history of 2 sites on Mars where conditions may have been favorable to the preservation of evidence of pre-biotic or biotic processes.
- Identify hydrologic, hydrothermal, and other processes that have operated at each of the sites.
- Identify and investigate Martian rocks and soils that have the highest possible chance of preserving evidence of ancient environmental conditions associated with water and possible pre-biotic or biotic activity.
- Respond to other discoveries associated with rover-based surface exploration.

2005 Mars Reconnaissance Orbiter

Mission Description
- Launch - August 2005; enter Mars polar orbit
- Prime Mission – 1 Mars years high resolution imaging and orbital characterization of Martian surface
- Science payload
  - High resolution visible-near IR imaging spectroscopy (VNIRIS) (0.4 to 3.6 microns, 10 nm resolution, 50m/pixel from 400 km altitude)
  - High-resolution visible imaging (HRI) - (60 cm /pixel from 400 km altitude) measurements for future landing site selection
  - Infrared sounding and imaging of Martian atmosphere (MCO recovery)
  - Other instruments under study

Primary Objectives:
- Recover the Mars Climate Orbiter (MCO) MARCI and PMIRR investigation, emphasizing Mars volatiles (water) and climate history
- Search for mineralogic and morphologic evidence of water-related processes on a global basis
- Advance our understanding of the physical processes controlling the present transport, distribution and past evolution of water on Mars
- Conduct detailed study of regions of high scientific interest, including the Mars Global Surveyor discovery sites associated with “modern” water
- Characterize potential landing sites with regard to both scientific merit and landing safety
- 10 year extended mission telecommunication relay and navigation beacon

Note: missions beyond 2005 are included here for informational purposes only and should be considered in the conceptual planning stages.

2007 Opportunity

- Smart Lander: Technology demonstration of hazard avoidance and hazard tolerance technologies necessary for a Mars Sample Return mission.
- CNES Orbiter and Netlanders: CNES led orbiter to demonstrate technologies needed for Mars Sample Return. CNES orbiter delivers the CNES lead Netlander mission and serves as an in-situ telecommunications relay.
- Mars Scouts Mission: described in this call for concept study abstracts.
- ASI Telecom Orbiter: telecommunications/navigation orbiter supplied by ASI that can provide in-situ telecommunications support for surface missions.

2009 Opportunity

- ASI Science/Telecom Orbiter: ASI science orbiter with telecommunications relay for surface missions.

<u>2011 Opportunity</u>

- Mars Sample Return
    - Sample return of at least 500 g of rock, soil, and atmosphere
    - Sample diversity assured by surface mobility - collection > 1 km radial from landing site (few months excursion)
    - Includes a sample from depth of > 2 m
    - Landing location accessibility: within ±15° Lat and < +1.5 km altitude (with respect to the MGS (MOLA-based) mean reference)
    - Landing accuracy < 50 km

- Competed scout opportunity

<u>2013 and beyond</u>

Additional sample return missions, orbiters, landers, scouts, etc.

GENERAL INSTRUCTIONS

1.0 CONCEPT REQUIREMENT

The following provides general instructions and information regarding preparation of your Concept in response to this request for the Mars Scout concepts. The effort to be performed, delivery schedule and/or performance period and contract type will be in accordance with one of the Specimen Contracts.

2.0 CONCEPT ABSTRACT FORMAT

Your Concept abstract shall consist of seven (7) pages in accordance with Exhibit VI. The first step of the selection process shall be the submission of a Notice of Intent. The second step is submission of a Concept Abstract. The third step is an oral presentation in an open forum to a review board at the workshop. The review board will then caucus and have the option to ask questions in a closed door session at the workshop on the same day as your oral presentation. The Concept is to be submitted in accordance with the instructions of this call for proposals.

3.0 SCHEDULE OF ORAL PRESENTATIONS

The sequence of presentations will be determined by random drawing of the review board chair shortly after receipt of Concepts on or about May 2. The sequence of presentations will be posted to the WWW site (http://spacesciences.nasa.gov/an/marsscoutsworkshop) by May 4. Only those individuals that have submitted a Concept Abstract conforming to the requirements of this call for proposals by the due date will be requested to make an oral presentation. Individuals are limited to the submission of only one concept. All individuals submitting valid Concept Abstracts will be invited to present at the workshop. Oral presentations are expected to begin at 8 AM on May 22, 2001.

4.0 SUBMITTING YOUR CONCEPT

4.1 Submit a Notice of Intent (NOI) by 5 PM Eastern Daylight Time, April 9, 2001. Proposers not submitting an NOI by the deadline will not be allowed to submit a written concept abstract or to present their concept at the workshop. The NOI should be a short, text only email sent to jparrish@hq.nasa.gov. The text should contain the Principal Investigator name, mail address, email, phone, and fax. Also included should be co-investigators and other major partners with contact information (to the extent known). Please include a descriptive title of your concept abstract and a maximum 250 word summary of the concept.

4.2 Organization and Format for the Written Concept Abstract.

4.2.1 Your written Concept Abstract should conform to the format and content instructions given in Exhibit VI. You should submit one electronic version in WORD, RTF, or PDF format via email attachment to jparrish@hq.nasa.gov. The subject of your email submittal should be “Mars Scouts Concept Abstract-PI Last Name-PI First Name” where “PI last name" and "PI first name" are filled in with your specific information. Include the following template (filled in with your specific information) as the text portion of your email:

"Please accept this Mars Scouts Concept Abstract entitled 'FILL IN TITLE HERE.' My Concept Abstract attachment is in FILL IN ATTACHMENT FORMAT HERE (i.e. WORD, RFT, or PDF).
CONCEPT ABSTRACT FILE NAME IS <FILL IN>
INSERT 250 WORD OR LESS ABSTRACT FROM NOTICE OF INTENT HERE

Sincerely,
PI Name
PI Mail Address
PI Phone
PI FAX
PI email
DATE and TIME of email submission"

4.3 Address and Identification

To help ensure timely receipt and processing of your Concept Abstract, please make sure you adhere to these instructions for email submittal of your Notice of Intent and Concept Abstract submittal. You will be notified by return email as to the receipt of your Notice of Intent and Concept Abstract.

4.4 Hand Carried Concepts

Hard copies or facsimile (fax) transmission of the Notice of Intent or Concept **WILL NOT** be accepted. Only email submissions are accepted per the instructions of 4.3 above.

4.5 Oral Presentation

4.5.1 Your oral presentation format and content should conform to the format and content instructions given in Exhibit VII. The number and content of presentation viewgraphs should be strictly adhered to. Deviation from the specified format could result in your presentation being deemed non-compliant. Your oral presentation should contain only information submitted in your written Concept Abstract.

4.5.2 You may allocate your material within the 20 minute presentation as you see fit; keeping in mind, however, the relative weight of each evaluation criteria, specified in paragraph 8.0 below and your ability to cover the material submitted. During the open forum oral presentation, proposers have the option of withholding proprietary data contained in the written concept. The review board will not ask questions during your presentation. Questions of clarification, if needed, will be asked in a 5 minute period at the end of your presentation. The review board also reserves the right to bring presenters back at the end of the day in a closed-door session for a brief question and answer period.

4.5.3 The presentation will not be audio/video recorded by either the presenter or by the review board.

4.5.4 6-10 studies will be selected not later than **June 8 , 2001**.

5.0 GENERAL INFORMATION

5.1 Concept Preparation and Related Costs

This call for Concept Abstracts does not commit the Government of the United States or the Government's Representative to pay any costs incurred in submitting your Concept Abstract, travel to the workshop, making studies or designs for preparing the Concept Abstract or in procuring or subcontracting for services or supplies related to the Concept Abstract.

5.2 Data

If the Concept Abstract contains data that either you or your subcontractors do not wish to be disclosed for any purpose other than Concept evaluation, you must mark the cover sheet of such information with the legend below:

"Data contained in pages __________ of this Concept Abstract for the Mars Scout Missions shall not be used or disclosed, except for evaluation purposes, provided that if a contract is awarded to this offeror as a result of or in connection with the submission of this Concept Abstract, the Government shall have the right to use or disclose this data to the extent provided in the contract. This restriction does not limit the Government's right to use or disclose any data obtained from another source without restriction."

5.3 Classified Information

There shall be no classified information in response to this call for concepts.

5.4 Requests for Clarification/Addenda.

During the Concept preparation period, requests to clarify certain aspects of these instructions or for additional information, <u>must be in writing</u> and sent to by email to jparrish@hq.nasa.gov. Responses providing additional information or clarification will be provided to all prospective proposers on the web site (http://spacesciences.nasa.gov/an/marsscoutsworkshop). In addition, any changes to the governing documents will be provided to all prospective proposers as addenda to this letter. Prospective proposers will be notified of the issuance of all addenda via the web site and the addenda content will be posted on the web site. NASA will not be responsible for explanations or interpretations by any other means.

5.5 Retention Concept Material

Except where specified otherwise, the material furnished in this Request for Concept Study Abstracts should not be returned to NASA.

6.0 LATE CONCEPT ABSTRACTS

Any Concept Abstract,. portion of a Concept Abstract, or unrequested Concept Abstract revision received at NASA after the time and date specified is late. Any part of a Concept Abstract received after the time and date specified will cause the entire Concept Abstract to be late. Late Concept Abstracts will not be considered for award, except under the following circumstances:

6.1 NASA determines that the late receipt was due solely to a delay by the Internet for which the offeror was not responsible. Timely evidence of email transmittal by the proposer must be evidenced.

6.2 NASA determines that the Concept Abstract was late due solely to mishandling by NASA after receipt at NASA, provided that timely transmission of the Concept Abstract submission email is evidenced.

6.3 No acceptable Concept Abstracts are received in a timely manner.

<u>NOTE</u>: If an emergency or unanticipated event interrupts normal NASA HQ processes so that solicitation responses cannot be received at the NASA HQ office designated for receipt by the exact time specified in the solicitation, and urgent NASA HQ requirements preclude amendment of the solicitation closing date, the time specified for receipt of Concept Abstracts will be extended to the same time of day specified in the solicitation on the first work day on which normal NASA HQ processes resume.

7.0 SOURCE EVALUATION AND SELECTION PROCESS

7.1 Source Evaluation

The Submitted Abstract and Oral Presentation constitutes the Mars Scout Concept. Concepts will be evaluated in the areas of technical and management as described in paragraph 8.0 below. In order to attain the highest quality study possible proposers are asked not to propose an amount less than $100,000.00. Conversely, due to current funding constraints proposers are asked not to propose an amount higher than $150,000.00. Accordingly, price per-se is not a significant consideration in the evaluation process. NASA plans to make source selection based on the offerors whose Concepts are determined to represent the best value to NASA. NASA will evaluate the Concepts utilizing the following process.

7.1.1 Before issuing this letter, NASA establishes specific criteria and their weighting for evaluation. After receipt at NASA, the Concepts are evaluated against the pre-set criteria outlined in paragraph 8.0 below

7.1.2 Responsibility is assessed within the meaning of Federal Acquisition Regulation 9.1. Award will not be made to a proposer deemed to be nonresponsible.

7.1.3 The review board may conduct closed-door discussions with each proposer following the oral presentation of the Concept Abstract. The purpose of the discussions is to assist the evaluators in fully understanding each Concept Abstract by:

7.1.3.1 Discussing the aspects of each Concept Abstract which contain omissions, ambiguities and uncertainties;

7.1.3.2 Verifying and identifying strengths and weaknesses that could affect work performance;

7.1.3.3 Verifying the validity of the proposed cost; and

7.1.3.4 Validating weaknesses of past performance.

7.1.4 After discussions, the results of the electronic Concept Abstract submittal, oral presentation, and discussions are used to arrive at a final evaluation.

7.2 Selection Process

The results of the final evaluation are submitted to the NASA Source Selection Official, who selects the proposer(s) for negotiation.

7.3 NASA reserves the right to reject all Concepts or to award a contract based on initial Concepts (without Concept clarifications).

8.0 EVALUATION CRITERIA

The evaluation criteria for this procurement are listed below. The factors shown under the criteria are not individually weighted for evaluation purposes and are not listed in any particular order.

Innovative mission concept – Criterion 1 (400 points)

- The degree to which the mission concept accomplishes the science.
- The feasibility and completeness of the mission concept.
- Identification of the enabling new technology required in the mission concept including potential sources of the new technology. Note that new technology is defined as technology not yet at TRL level 6. TRL level 6 is defined as

"System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)."

- Identification of the enabling or enhancing infrastructure required in the mission concept.
- Value to Mars Program and relationship to past, present, and future missions.

New and Compelling Science Investigation- Criterion 2 (300 points)

Mars Scouts are innovative science missions. Individually, Scout missions comprise the investigation required to address high priority science as defined by the Mars Exploration Payload Analysis Group document pursuant to Exhibit V. They may also address new discoveries, particularly those discoveries that warrant rapid follow-up.

- Potential for investigation to fundamentally improve our understanding of Mars (make discoveries that fundamentally change current thinking about Mars.)
- Innovative science approaches that maximize the utility of a selected observation investigation platform.
- Ability to follow-up on new and evolving ideas about Mars.
- Focused science investigation.

Feasibility and completeness of the study plan – Criterion 3 (300 points)

- Identification of study team members.
- Relationship of the study team to the study Work Breakdown Structure (WBS).
    - The degree to which the experience and skills of the team members and the experience of the organization(s) are appropriate to the study tasks and assure a comprehensive and technically competent study effort.
    - Time available for each person involved in the study is commensurate with responsibilities.
- Past performance of the proposed organization in similar studies.
- Study plan for identifying new technologies.
- Study plan for quantifying ROM total mission cost, ROM cost per WBS, and ROM cost per fiscal year.
- Study plan for specifying schedule, major risk items and risk reduction strategy.
- Completeness of management approach for the study, including lines of responsibility and communication within and between organizations and with management.
- Plan for meeting the proposed study schedule outlined in this request for Mars Scouts Concepts.

9.0 EXCEPTIONS TO TERMS AND CONDITIONS

A large number of exceptions or one or more significant exceptions to the General Provisions and/or Additional General Provisions may make your Concept unacceptable for evaluation. **You must provide a detailed explanation, including the rationale, for any exceptions you take.** Proposers who submit Concepts with exceptions may be selected for negotiations. However, if an agreement cannot be negotiated, your Concept may be rejected.

CONCEPT ABSTRACT INSTRUCTIONS

1. INTRODUCTION

This portion of the Concept instructions sets forth the requirements to be followed in preparing the Concept. Concept abstract format and content information is included in Exhibit 6.

COST INSTRUCTIONS (not included in page count)

1. CONCEPT PRICING

Provide a breakdown of all labor categories and associated hours to perform the effort defined in the Specimen Contract. This information should be submitted using the format on the next page (or equivalent).

Include a copy of the data as the last page(s) of your Concept Abstract submittal. NOTE THAT THESE COST PAGES DO NOT COUNT AGAINST THE PAGE LIMIT OF YOUR ABSTRACT. If the Concept study includes separate phases or options, a time-phased summary must be submitted for each.

2. INDEPENDENT FUNDING

If you elect to submit a Concept in which you fund a portion of the effort, the Concept Abstract should clearly show the cost of the full requirement, and indicate which part of the effort is to be funded by the contractor and which part is to be funded by NASA. Note this cost Concept may be submitted in addition to or in lieu of a non Contractor-funded Concept.

3. PARTIAL PAYMENTS

Partial Payments will not be allowed.

4. PROGRESS PAYMENTS

Progress payments will be allowed if requested.

5. SUPPLEMENTAL BUSINESS/COST INFORMATION

5.1 Financial Statement

Submit a copy of your annual financial statements for the last three years and any information regarding additional resources required to perform the proposed effort such as an established line of credit or other financial resource.

ATTACHMENTS TO THE SOLICITATION

The following forms are attached to this solicitation and require completion and return with your response:

☒ Acknowledgment

☒ Cost Element Breakdown

COST ELEMENT BREAKDOWN

SUPPORT DATA REF.	COST ELEMENT	PERIOD = month, quarter, year, etc.					TOTAL
	DIRECT LABOR HOURS (by labor category)						
	TOTAL HOURS						
	DIRECT LABOR RATE (by labor category)						
		$	$	$	$	$	$
		$	$	$	$	$	$
		$	$	$	$	$	$
		$	$	$	$	$	$
	DIRECT LABOR DOLLARS (by labor category)						
		$	$	$	$	$	$
		$	$	$	$	$	$
		$	$	$	$	$	$
		$	$	$	$	$	$
	TOTAL DIRECT LABOR $	$	$	$	$	$	$
	OVERHEAD						
	base & %	$	$	$	$	$	$
	base & %	$	$	$	$	$	$
	TOTAL OVERHEAD	$	$	$	$	$	$
	MATERIAL	$	$	$	$	$	$
	MATERIAL BURDEN	$	$	$	$	$	$
	SUBCONTRACT	$	$	$	$	$	$
	SUBCONTRACT BURDEN	$	$	$	$	$	$
	OTHER DIRECT COST						
	TRAVEL, etc.	$	$	$	$	$	$
		$	$	$	$	$	$
	TOTAL ODC	$	$	$	$	$	$
	SUB-TOTAL COST	$	$	$	$	$	$
	G&A base & %	$	$	$	$	$	$
	TOTAL COST	$	$	$	$	$	$
	PROFIT/FEE base & %	$	$	$	$	$	$
	TOTAL PRICE	$	$	$	$	$	$

Attachment A-1

ACKNOWLEDGMENT

(This Completed Acknowledgment Must Accompany Your Offer)

1. Offeror name: ____

   (NOTE: Include the full name of the contracting entity, not just the operating division. Such full name is the name that would go in the contract if awarded to your firm.

2. Name and telephone number of persons authorized to conduct negotiations:

   Name: ________________________ Phone Number: ____________________

   ________________________ ____________________

3. The Offeror acknowledges that the Specimen Contract, including the Special Provisions, General Provisions, Additional General Provisions and Attachments, are acceptable in case of contract award.

   NOTE: The General Provisions and Additional General Provisions cannot be altered without NASA approval.

   ☐ Yes ☐ No (If no, attach a detailed explanation of the exceptions, including rationale.)

4. Name, address, phone number of cognizant Government Audit Agency representative:

   ____

5. a. Audit Reports. The Offeror agrees that all Government audit reports directly related to its offer(s) and contract, if any, resulting from this solicitation are authorized to be released. ☐ Yes

   b. Are you subject to Office of Management and Budget Circular No. A-133? ☐ Yes ☐ No

   If yes, the "year ending" date of the most recent report is: ________________________ (enclose a copy of the most recent report).

6. The Offeror acknowledges that the offer will be valid for _________ days after the date for receipt of offers specified on the cover page of this solicitation.

7. The Offeror acknowledges receiving the following Addenda to the RFQ/RFP:

   Addenda No(s).: ____

   NOTE: Failure to acknowledge receipt of all Addenda may result in your offer being rejected.

8. a. Preference will be given to United States (U.S.) domestic end products under the Buy American Act (BAA) for those items to be used in the U.S. and under the Balance of Payments Program (BPP) for supplies and services (including construction) to be used outside the U.S.

b. The Offeror certifies that each end product/service to be supplied is domestic, as defined in the BAA and BPP, except for those which the Offeror has listed, with country of origin shown, on a separate attachment to this Acknowledgment and that components of unknown origin were considered by the Offeror to have been mined, produced, or manufactured outside the U.S. The Offeror also certifies whether the offeror qualifies for any special treatment as a signator to any international agreements, such as designated country status under the Trade Agreements Act.

9. Can you supply the requested items through a Federal Supply Schedule (GSA) Contract?

☐ Yes ☐ No If yes, list FSS (GSA) Contract No. ________________________________

10. The Offeror certifies that it is the type of business indicated below. Please check the appropriate box[es]), and fill in the blank if appropriate.

☐ Large Business
☐ Small Business (as defined by FAR)
☐ Nonprofit Organization
☐ Small Disadvantaged Business (as defined by FAR)
☐ Women-Owned Business (as defined by FAR)
☐ Educational Institution (as defined by FAR)
☐ HBCU/OMI
☐ Sole Ownership
☐ Partnership
☐ Corporation, incorporated under the laws of the state of ____________________________

OFFEROR CERTIFICATION

The undersigned certifies that he/she is authorized to certify and to commit his/her company regarding the information on this form and for the total offer amount submitted in response to this solicitation.

Date ____________________ Firm ____

(Include full name of contracting entity, not just operating division. Such full name is name that would go in contract if awarded to your firm)

Name ____

Title ____

Signature ____

Telephone No. ____

Exhibit I - Mars Program DRAFT Scout Requirements

- Each Mars Scout mission shall contribute to the scientific and technology objectives of the Mars Exploration Program.

- Launch a Mars Scout mission to Mars no earlier than December 1, 2006 and no later than November 30, 2007.

- Collect and transmit back to Earth information concerning anomalies during mission critical events.

- Fit within the approved funding profile.

- New technology should be incorporated into planned missions only after it has reached suitably mature Technology Readiness Levels (TRL).

- Avoid major technical or programmatic risk.

  - For pre-project concept development studies, design margins for flight system mass, power, and total mission cost should be held to at least 30% where $\% = 100 \times \frac{(\text{Allocated - Estimated})}{\text{Allocated}}$

- Feed forward validated technologies and lessons learned to future missions.

- Missions are developed and conducted with major participation by industry.

- Radioisotope Heater Units (RHUs) may be used, as may advanced Radioisotope Power Sources (RPS), once available. Any use of radioisotope power or heat sources shall comply fully with applicable requirements for the handling and launch of nuclear materials.

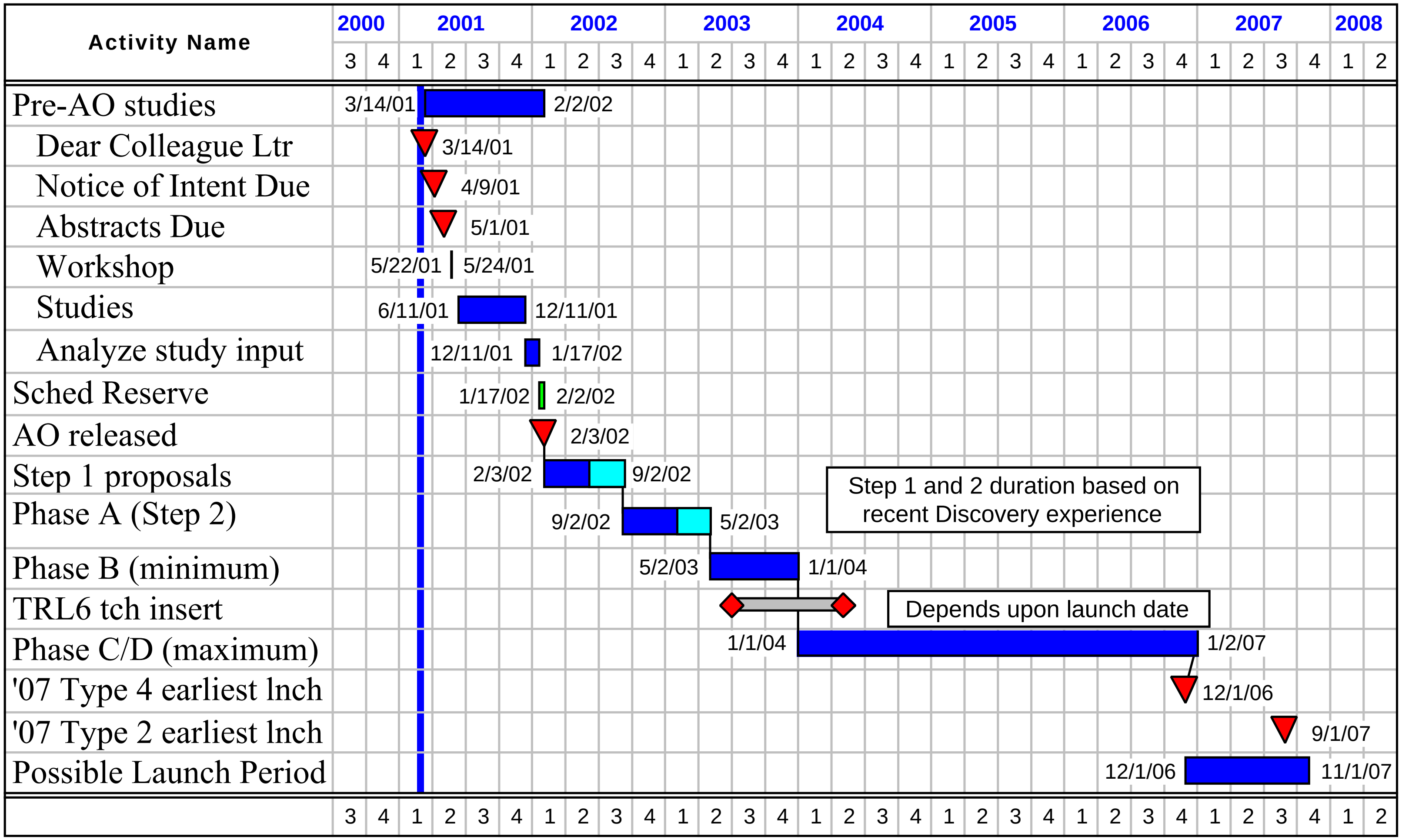
- Each Mars orbiter mission shall include a communications relay capability designed to operate at least one Mars year on-orbit. This communications relay capability is provided by the Mars Program.

- The communications relay package required on a Mars Scout science orbiter has the following properties:
  - Mass of 5 kg (including mass contigency)
  - Operating power of 75 W (used only during communications with a surface asset)
  - Standby power of 10 W (power drawn when not communicating with surface asset)
  - Volume of 22x17x14 cm (not including patch antenna)

Note that the communications relay package should not influence the design or observing profile of the science orbiter.

Disseminate Mars Scouts scientific data to appropriate data centers and to the public as soon as possible.

Exhibit II - Mars Scouts 2007 overall schedule



The Mars Scouts overall schedule provides for PI-led studies before an AO. Then, a nominal two-step process leads to selection for a flight mission. Note that the possible launch period is from December 1, 2006 to November 30, 2007.

Exhibit III - 2007 Trajectory and Launch Vehicle

These files provide you access to what are informally called "porkchop" plots, which are contours of trajectory performance and geometry data as a function of launch and arrival dates resulting in a transfer trajectory between two bodies orbiting the Sun. These particular plots refer to Earth-to-Mars ballistic (no deterministic Δv required) transfers with launch opportunities in 2007.

Here are the data types provided in these plots:

TTIME = Total trajectory transfer time (i.e. time of flight) [days]

C3L = Launch (departure) energy [km^2/s^2]

- it is the square of the departure hyperbolic excess velocity, which is the planetocentric velocity at infinity (i.e. after planetary escape),

$$V_\infty^2 = C3L = V_{inj}^2 - 2*GML/R_{inj}$$

where:

V_{inj} =conic injection velocity [km/s]
R_{inj} =planetocentric injection radius [km]
GML =gravitational constant times mass of departure body [km^3/s^2]

- Note: Launch vehicle capability C3 must exceed C3L requirement on chart

SEP = Sun-Earth-Probe Angle [deg]

- Parameter used to determine solar conjunction (i.e. SEP < 5 deg)

Ls = Mars True Solar Longitude [deg]

- This is used to define the Mars season (i.e. position of Mars in it's orbit), where:
  - Ls = 0 deg is beginning of Northern Spring (Southern Autumn),
  - Ls = 90 deg is the beginning of Northern Summer (Southern Winter),
  - Ls = 180 deg is the beginning of Southern Spring (Northern Autumn), and
  - Ls = 270 deg is the beginning of Southern Summer (Northern Winter)

DLA = Declination of Launch Asymptote [deg]

- Planetocentric declination of the launch asymptote (V_∞ vector at launch), which is a specific form of latitude wrt the mean planetary equator of epoch (of J2000 for Earth and of date for all other bodies) of the escape asymptote (i.e. the departure Vinf vector)

RLA = Right Ascension of Launch Asymptote [deg]

- Planetocentric right ascension of the launch asymptote (V_∞ vector at launch), which is a specific form of longitude measured in the Earth equator plane wrt to the Vernal Equinox (the ascending node point of the Ecliptic - Earth orbit plane - upon the Earth equator plane, both of epoch J2000)

VHP = Arrival hyperbolic excess velocity [km/s]

- Planetocentric hyperbolic excess velocity (V_∞) magnitude at arrival body. It is obtained by vectorial subtraction of the heliocentric arrival planet orbital velocity vector from the spacecraft's heliocentric arrival velocity at the (nonattracting) target body. It represents the planet-relative velocity at approach and can be used to compute spacecraft velocity at lesser distances, using the Vis-Viva integral: V = sqrt(VHP**2 + 2*GMP/R)

DAP = Declination of Arrival Asymptote [deg]

- Planetocentric declination of the arrival asymptote (V_∞ vector at arrival) towards the arrival planet (for definitions see DLA, above)

RAP = Right Ascension of Arrival Asymptote [deg]

- Planetocentric right ascension of the arrival asymptote (V_∞ vector at arrival) towards the arrival planet (for definitions see RLA above)

Figure 1: Introduction to "porkchop" plots, definitions and descriptions.

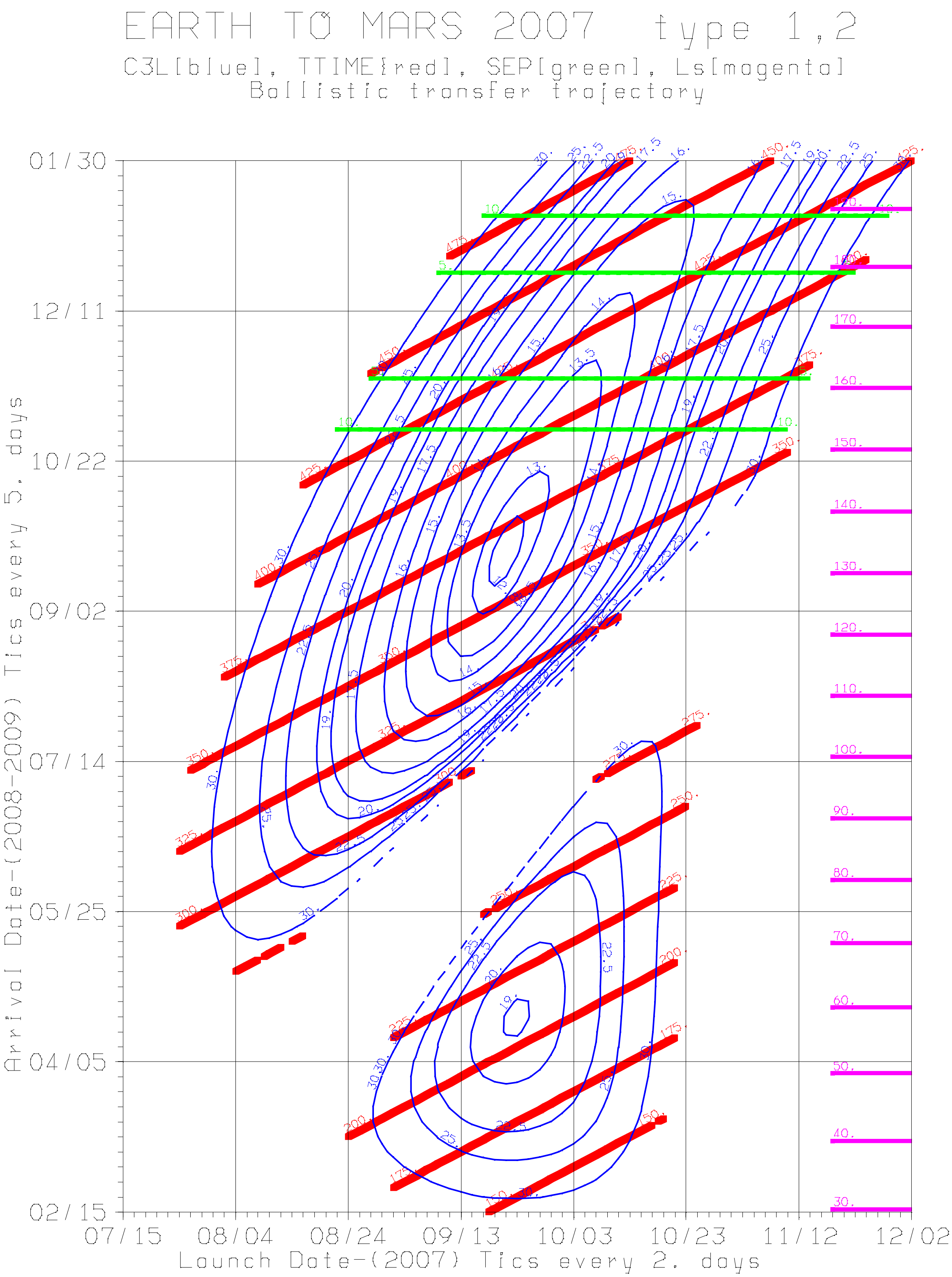


Figure 2: Launch energy (C3) contours for the Type I and II Earth-Mars ballistic trajectories in 2007.

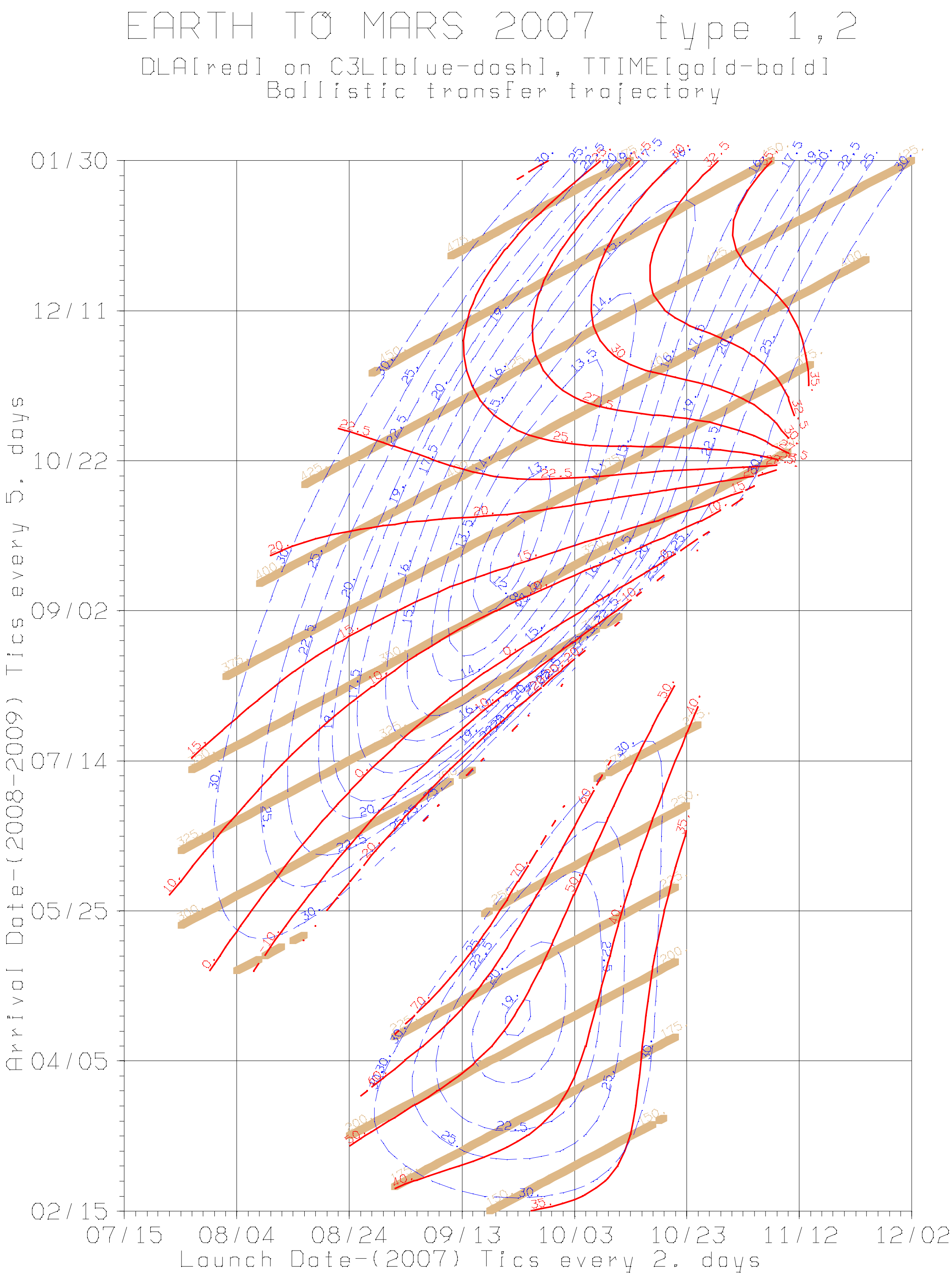


Figure 3: Declination of launch asymptote (DLA) contours for the Type I and II ballistic trajectories in 2007.

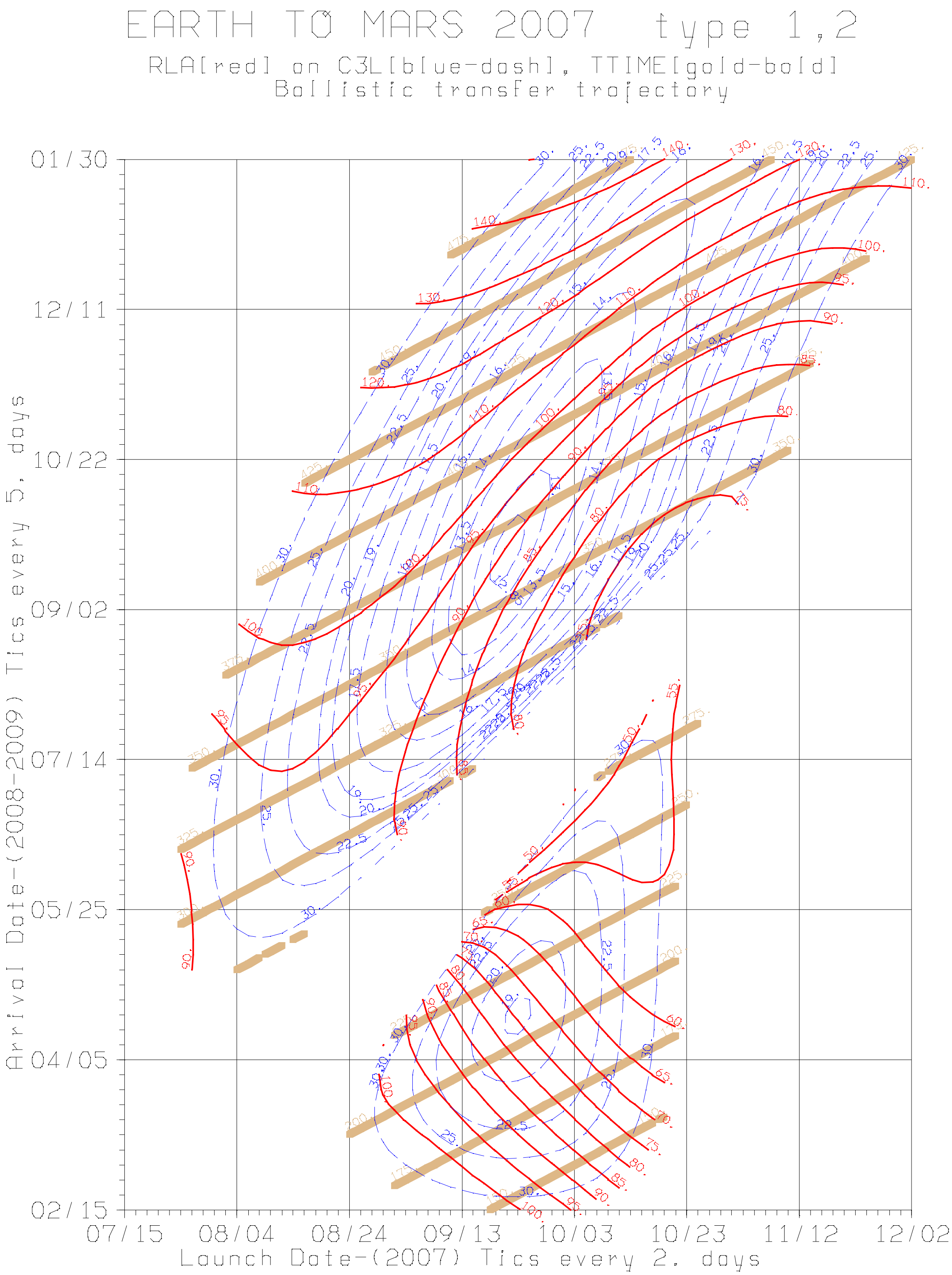


Figure 4: Right ascension of launch asymptote (RLA) contours for the Type I and II ballistic trajectories in 2007.

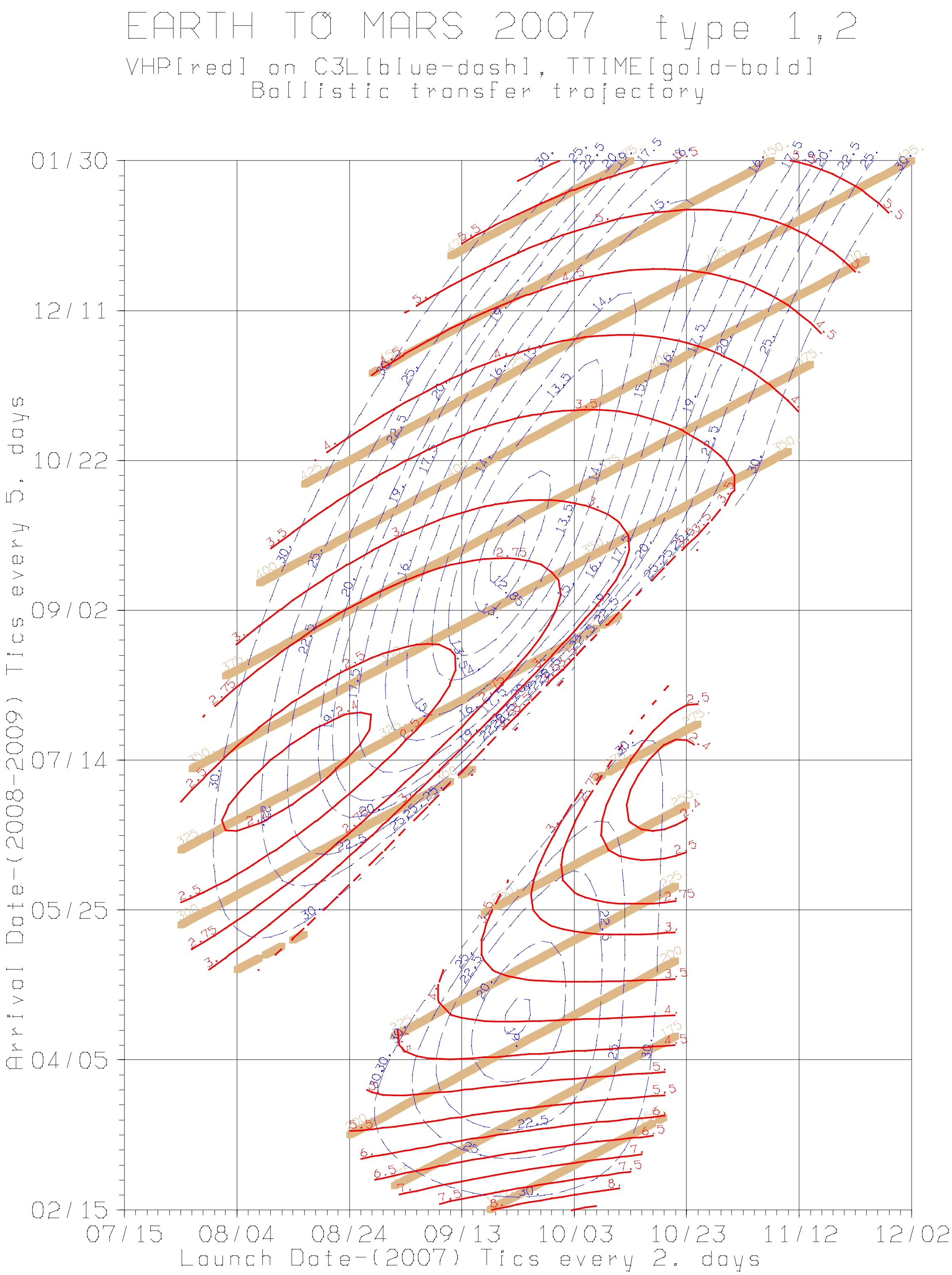


Figure 5: Arrival hyperbolic excess speed (V_∞) contours for the Type I and II ballistic trajectories in 2007.

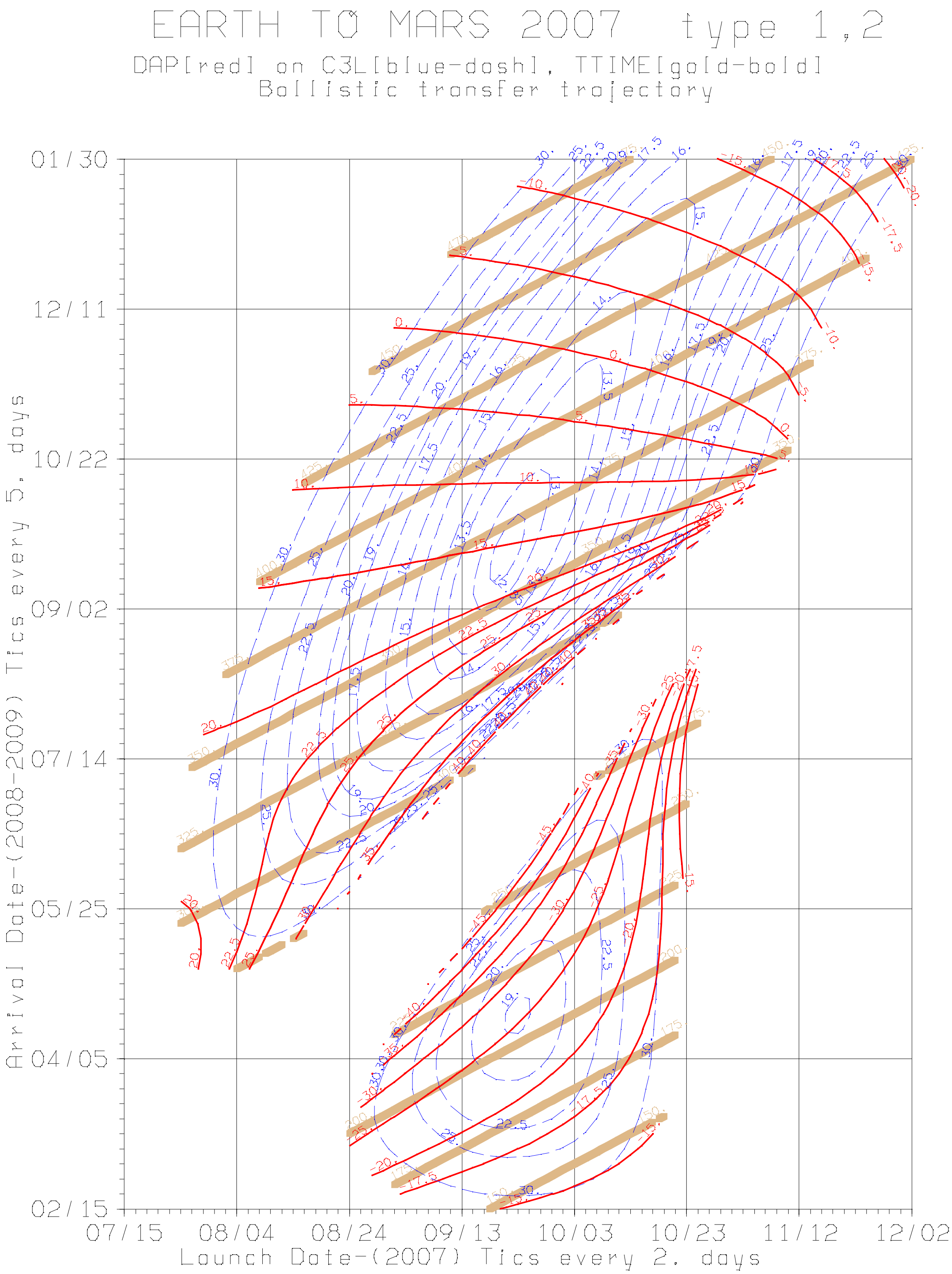


Figure 6: Declination of arrival asymptote (DAP) contours for the Type I and II ballistic trajectories in 2007.

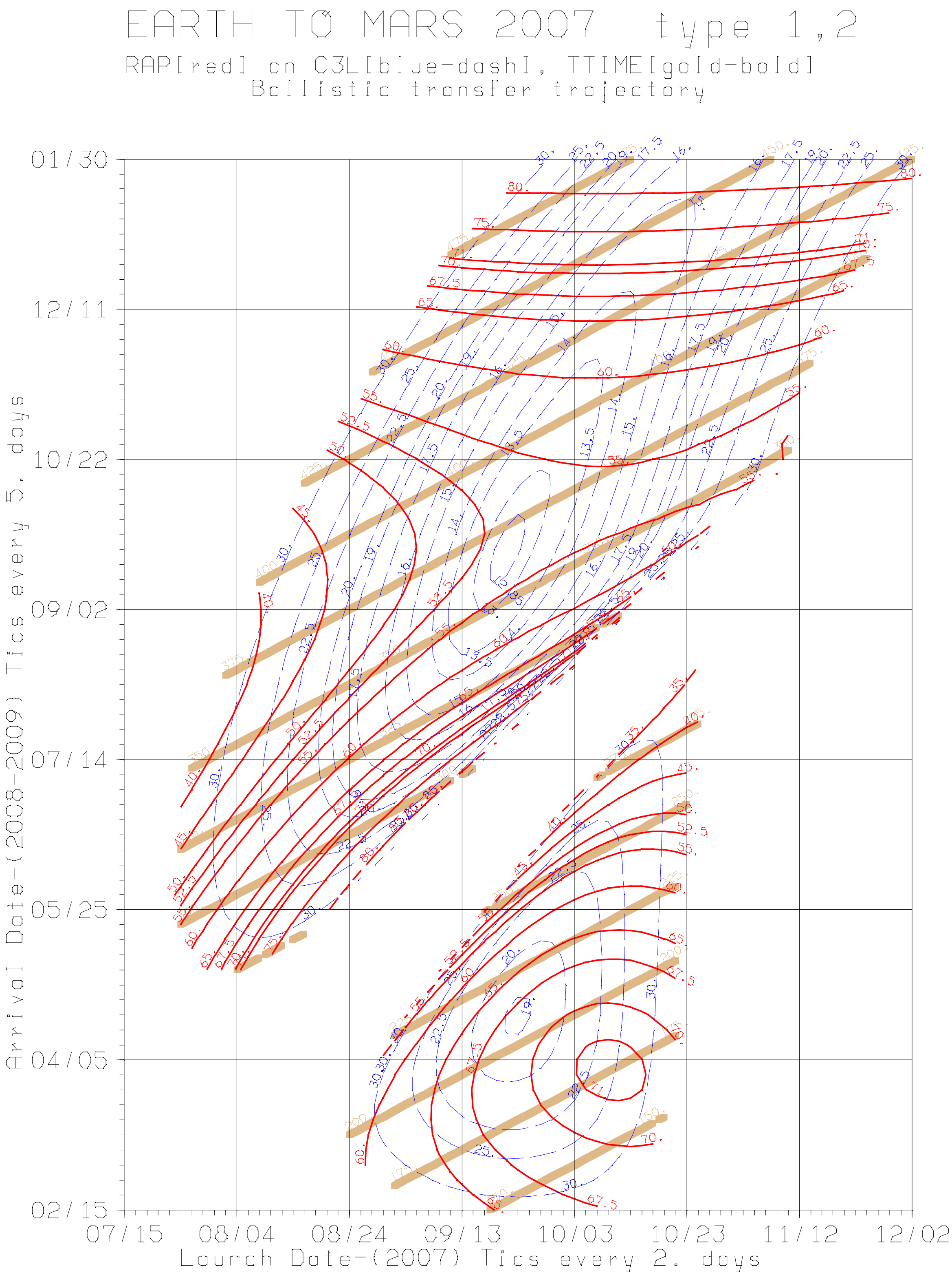


Figure 7: Right ascension of arrival asymptote (RAP) contours for the Type I and II ballistic trajectories in 2007.

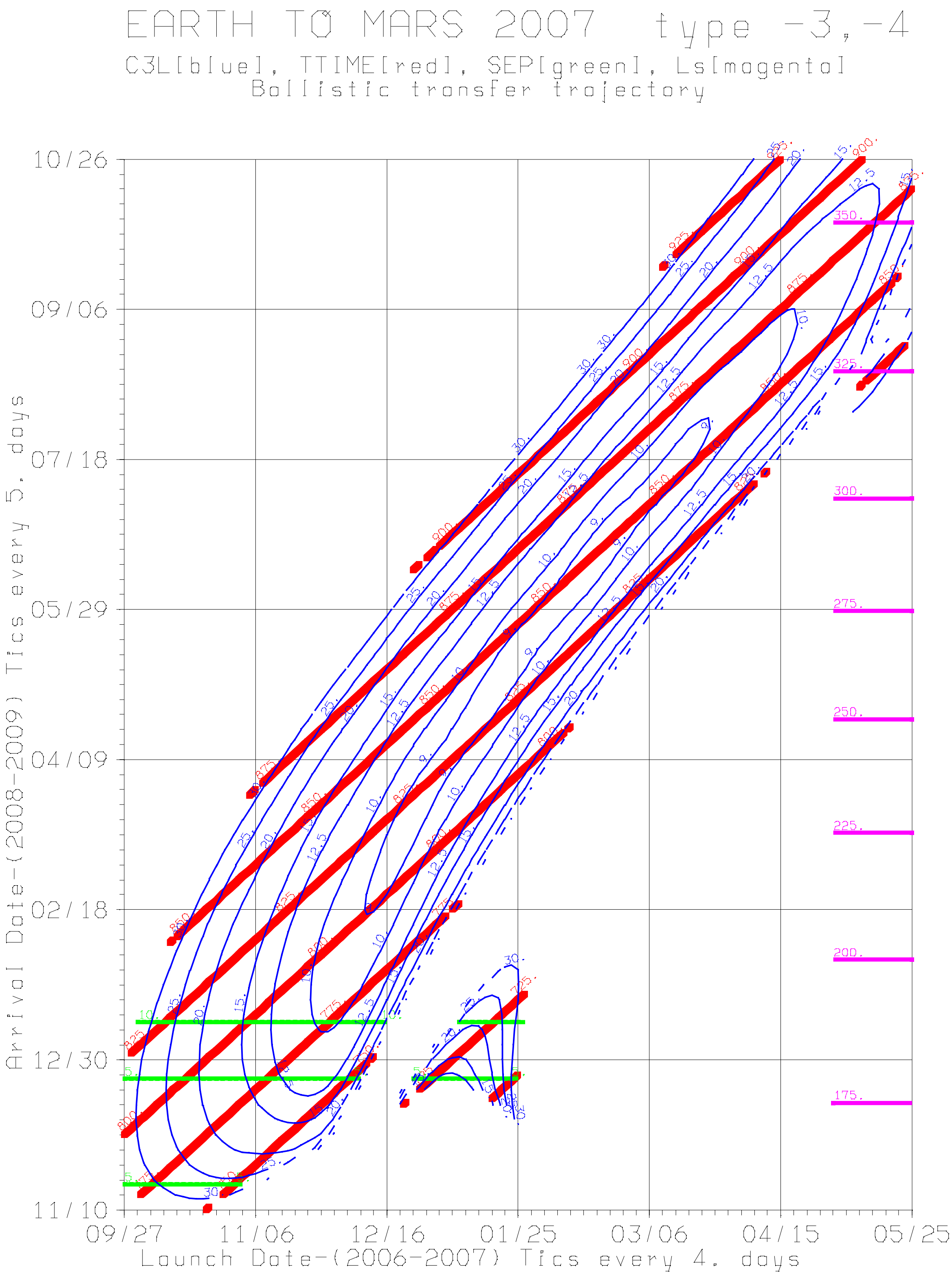


Figure 8: Launch energy (C3) contours for the Type -III and -IV Earth-Mars ballistic trajectories in 2007.

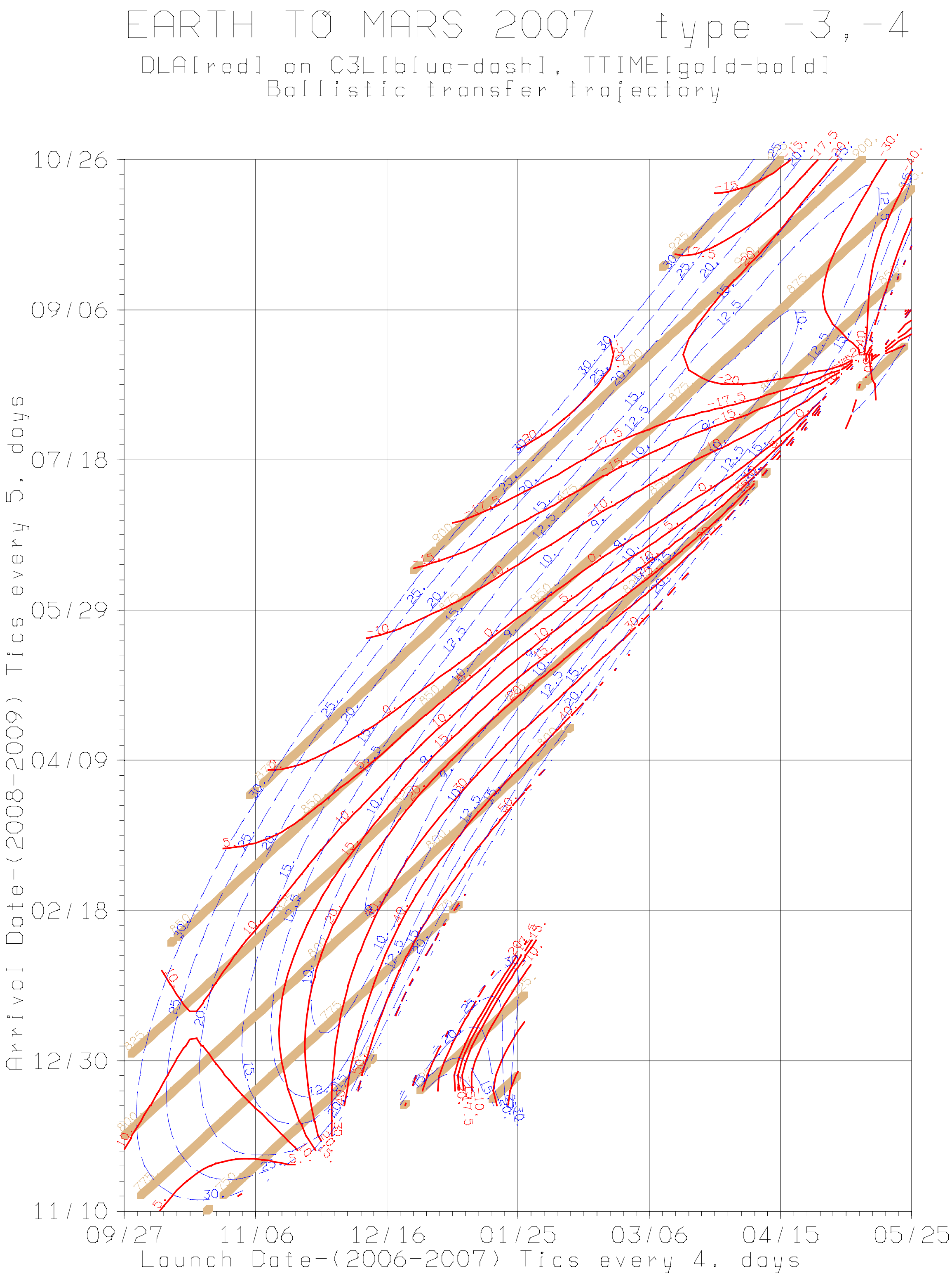


Figure 9: Declination of launch asymptote (DLA) contours for the Type -III and -IV ballistic trajectories in 2007.

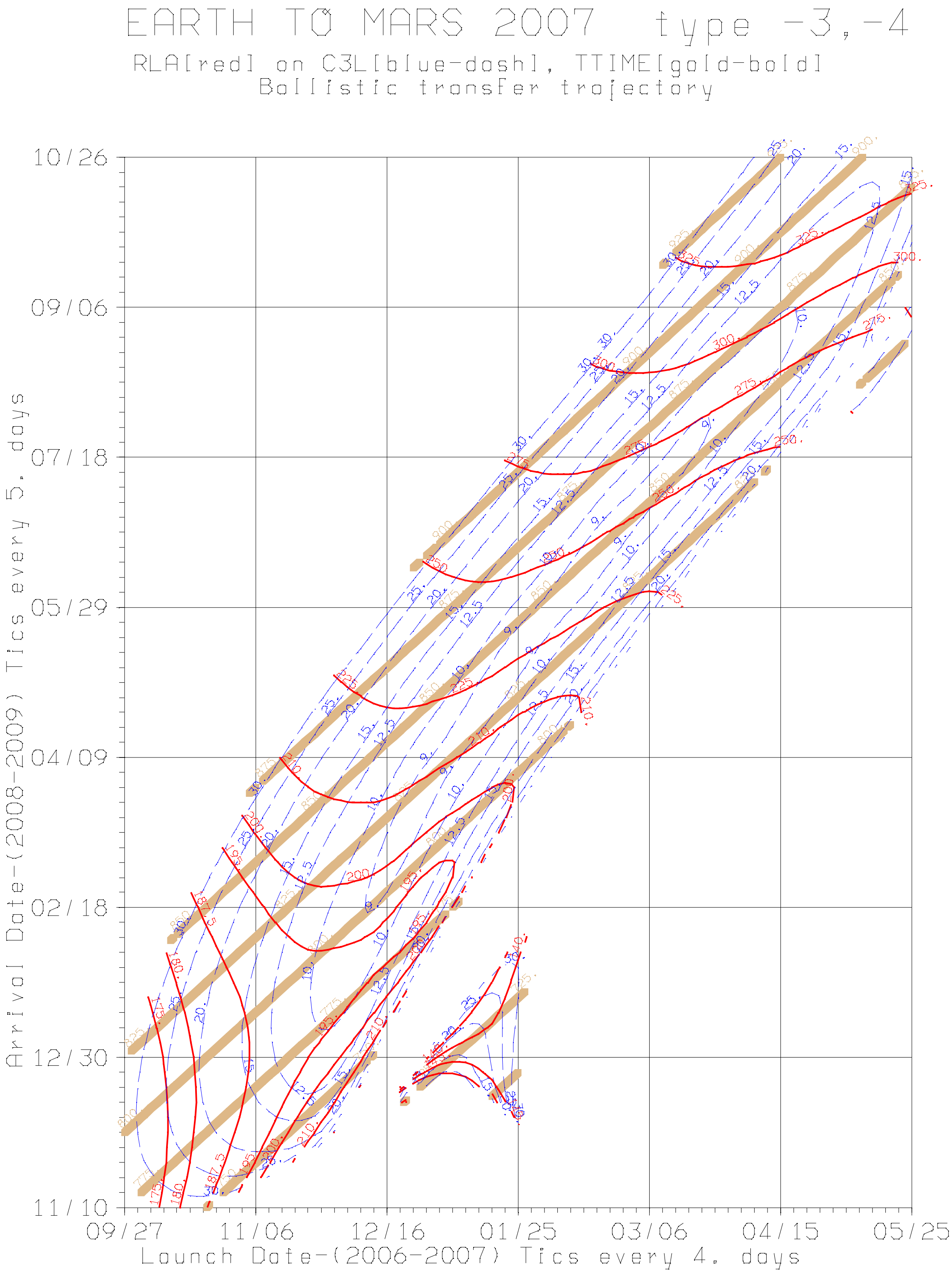


Figure 10: Right ascension of launch asymptote (RLA) contours for the Type -III and -IV ballistic trajectories in 2007.

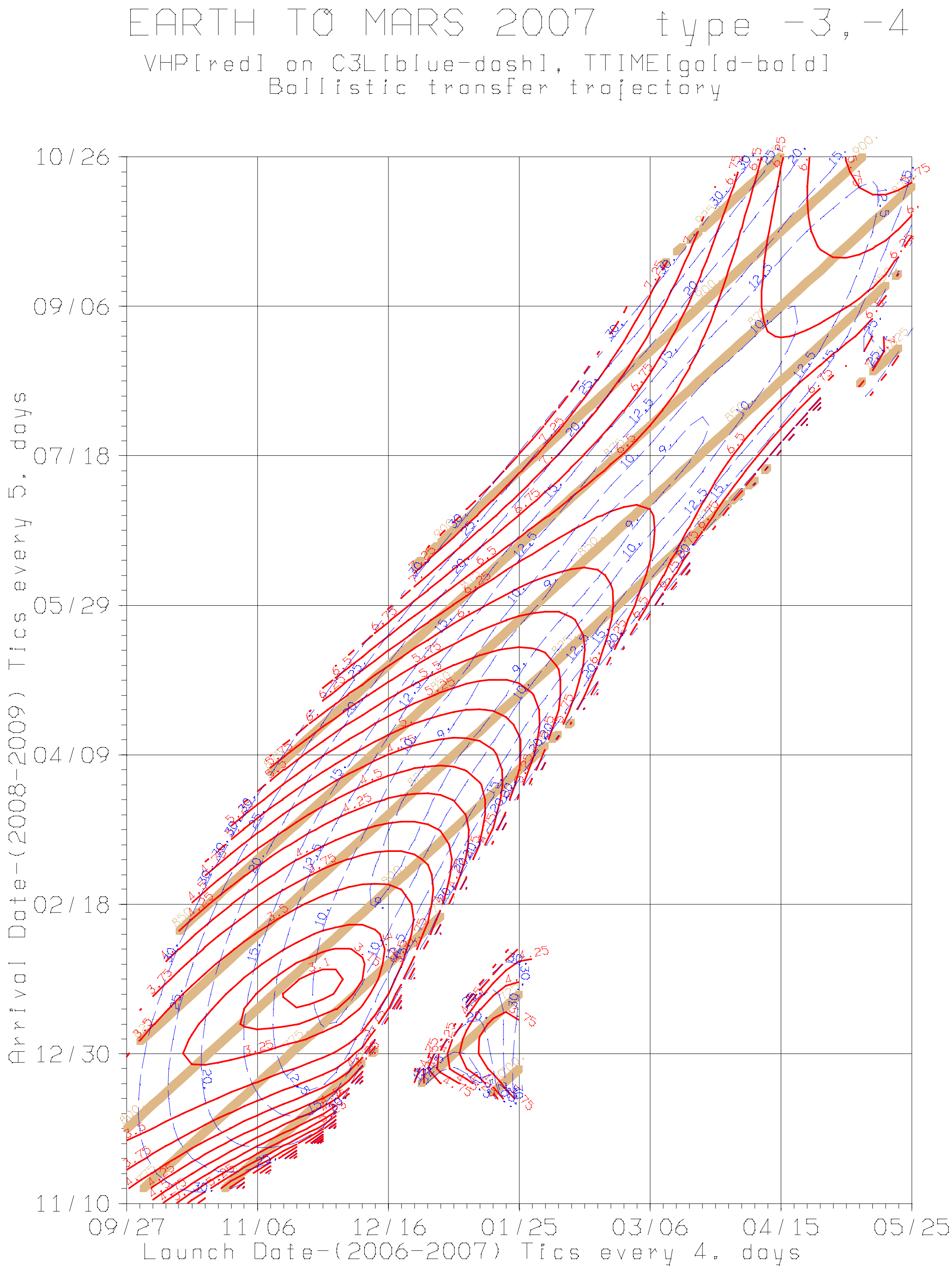


Figure 11: Arrival hyperbolic excess speed (V_∞) contours for the Type -III and -IV ballistic trajectories in 2007.

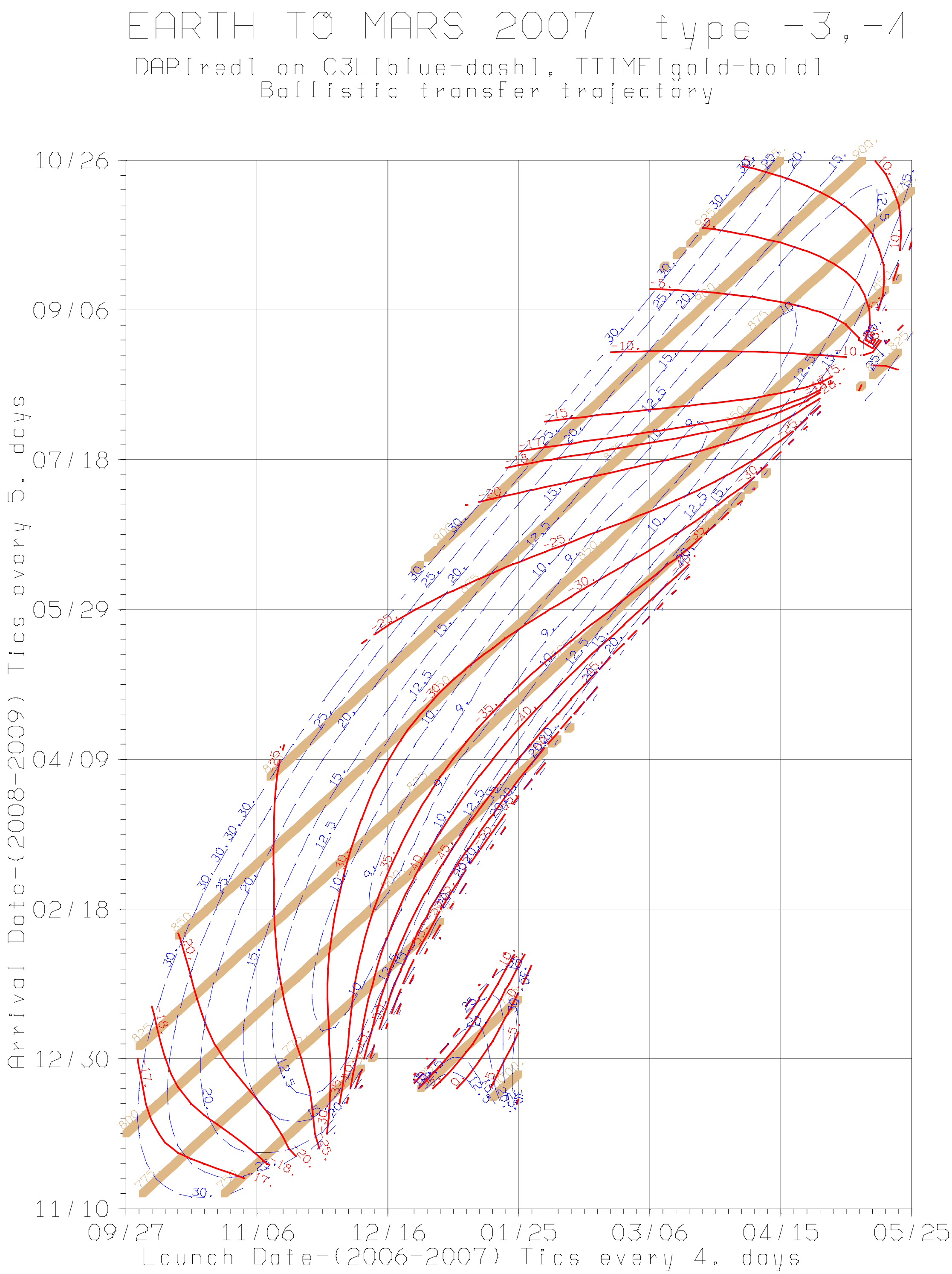


Figure 12: Declination of arrival asymptote (DAP) contours for the Type -III and -IV ballistic trajectories in 2007.

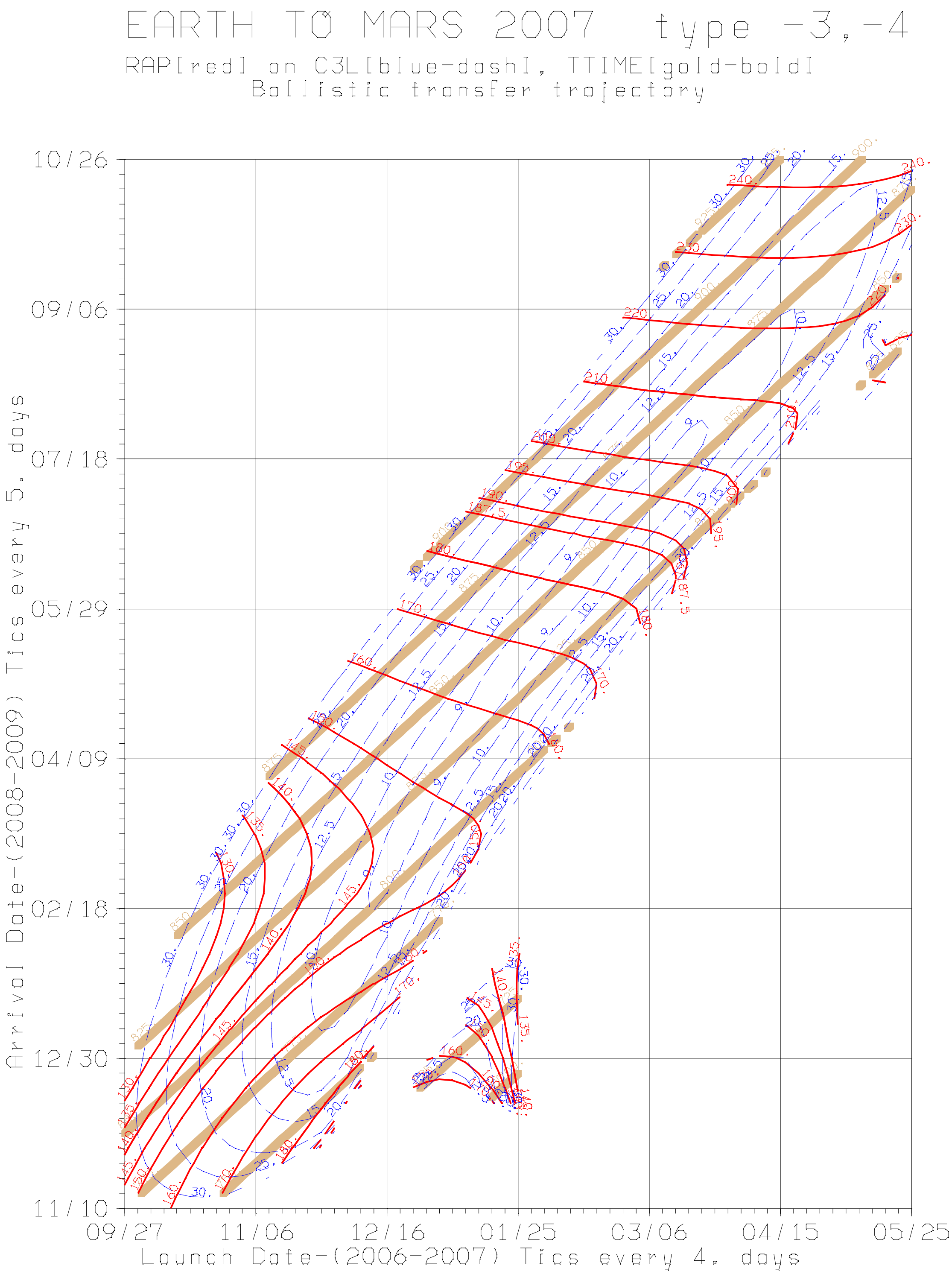


Figure 13: Right ascension of arrival asymptote (RAP) contours for the Type -III and -IV ballistic trajectories in 2007.

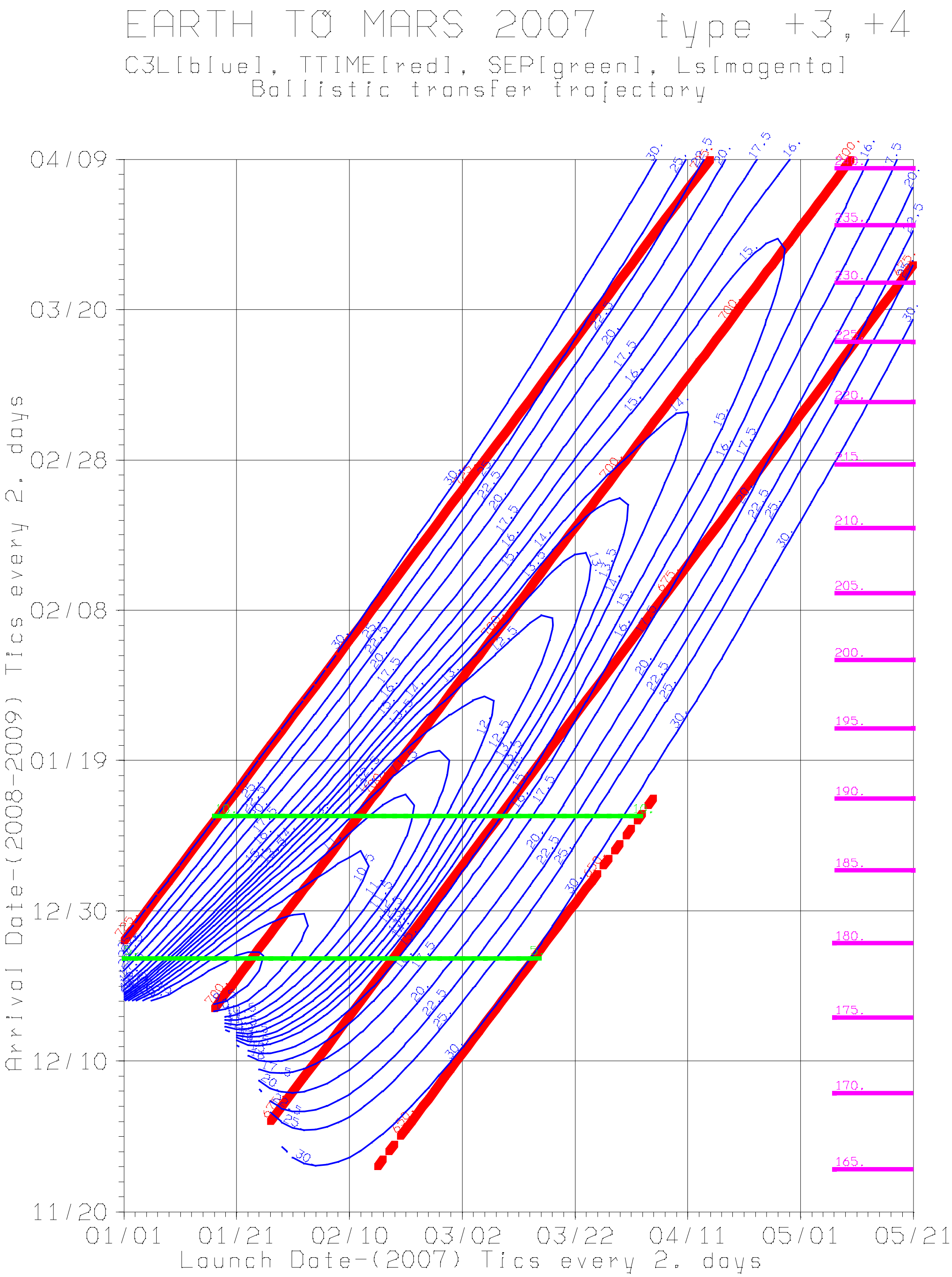


Figure 14: Launch energy (C3) contours for the Type +III and +IV Earth-Mars ballistic trajectories in 2007.

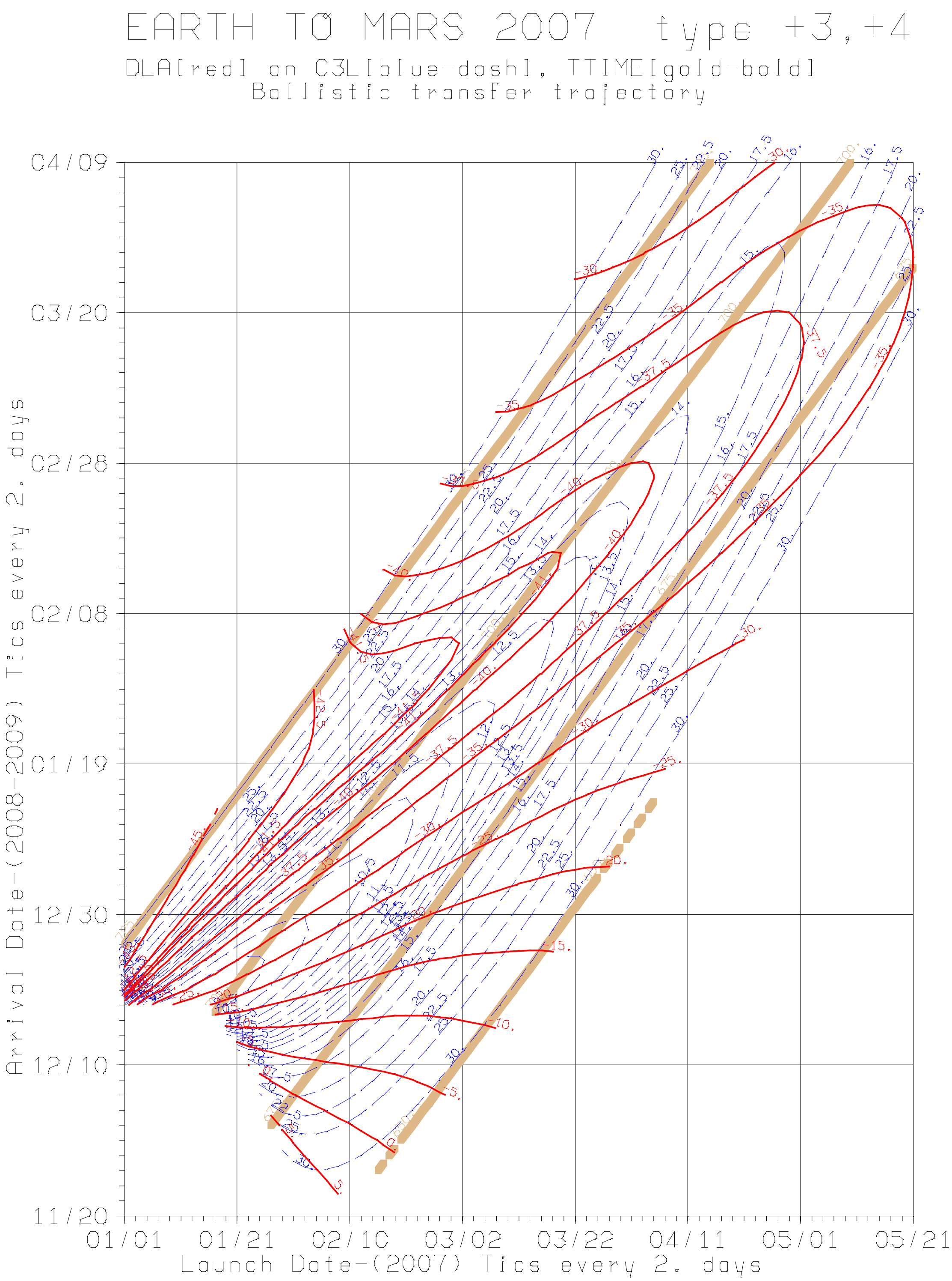


Figure 15: Declination of launch asymptote (DLA) contours for the Type +III and +IV ballistic trajectories in 2007.

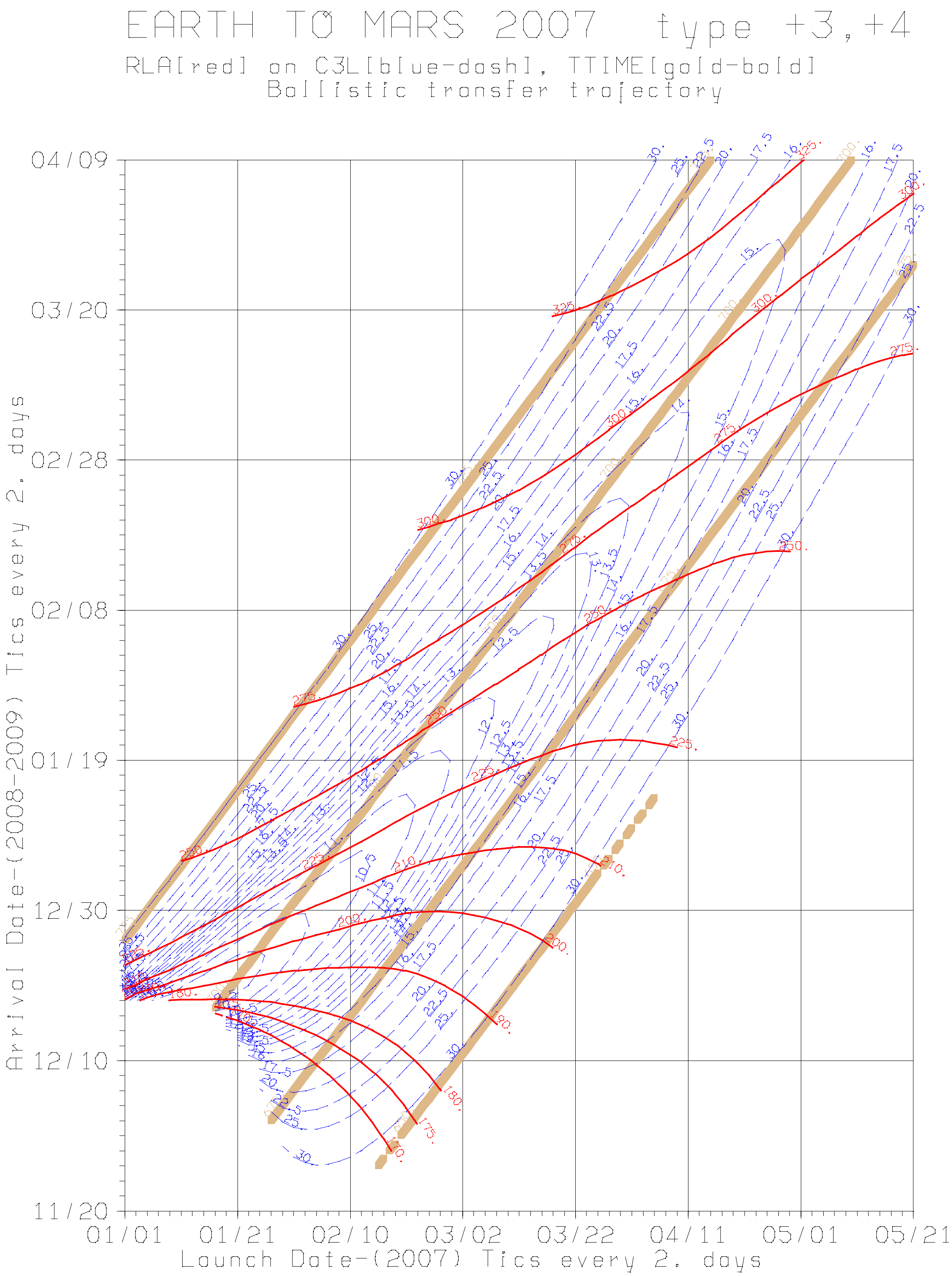


Figure 16: Right ascension of launch asymptote (RLA) contours for the Type +III and +IV ballistic trajectories in 2007.

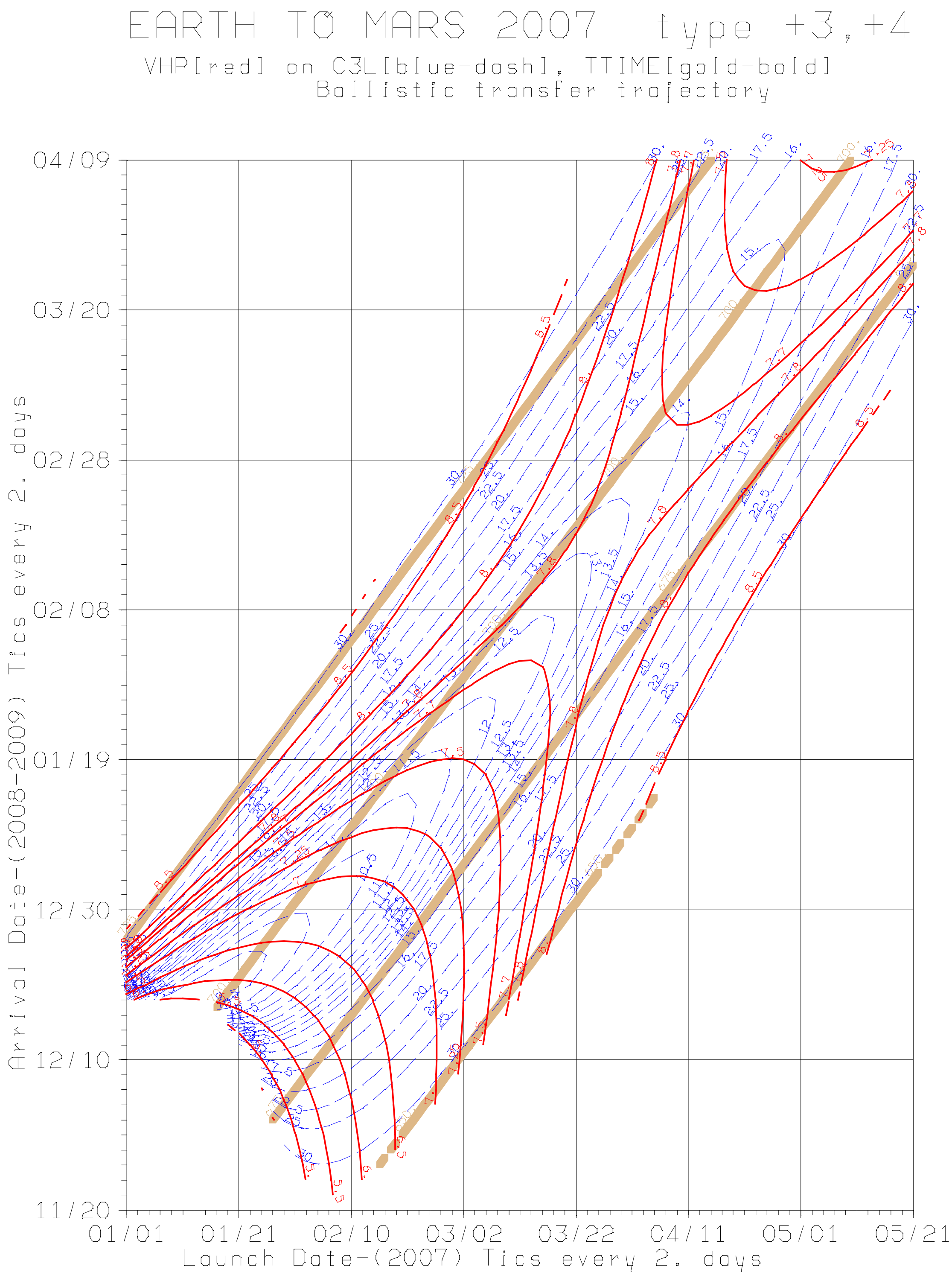


Figure 17: Arrival hyperbolic excess speed (V_∞) contours for the Type +III and +IV ballistic trajectories in 2007.

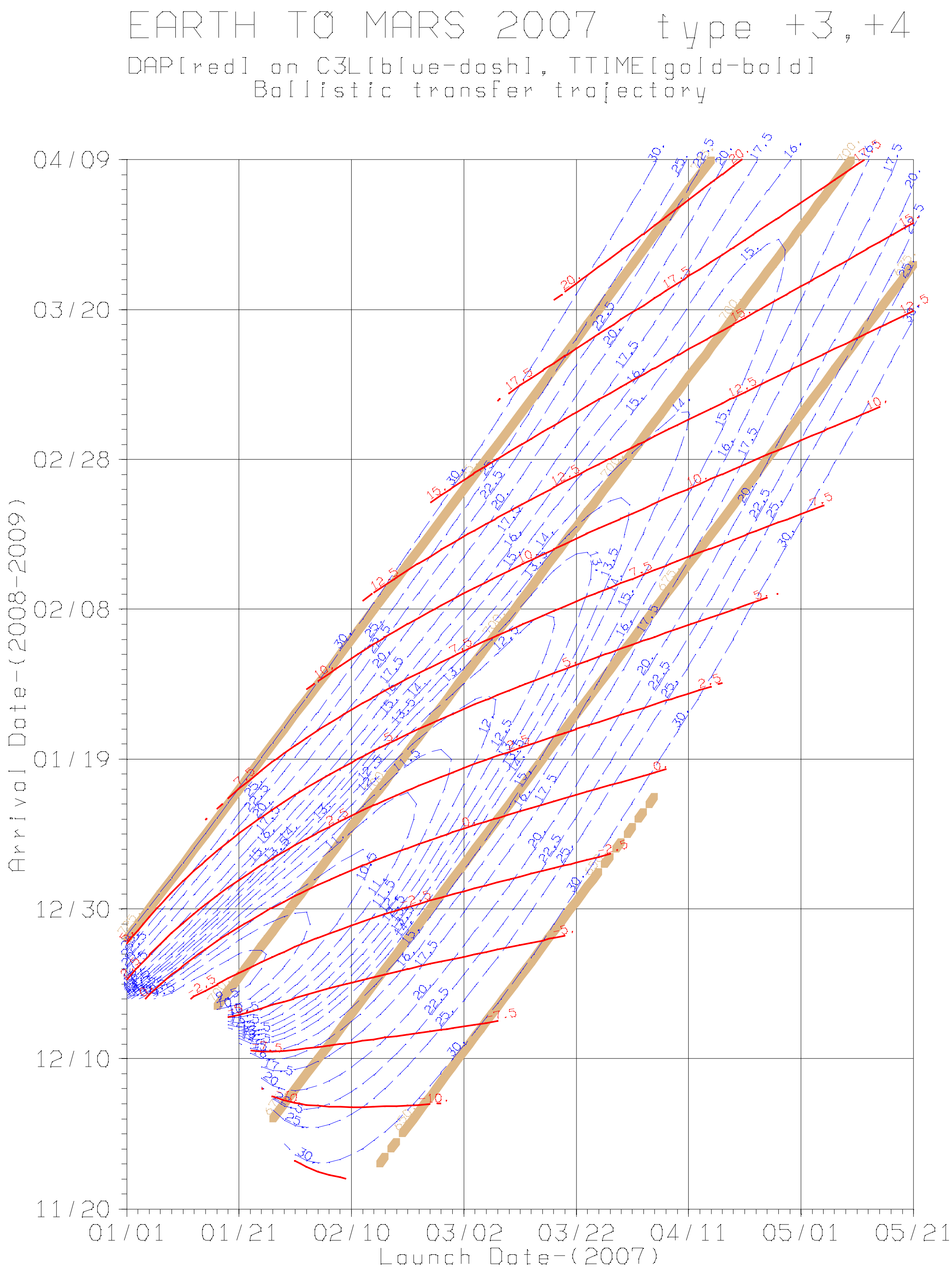


Figure 18: Declination of arrival asymptote (DAP) contours for the Type +III and +IV ballistic trajectories in 2007.

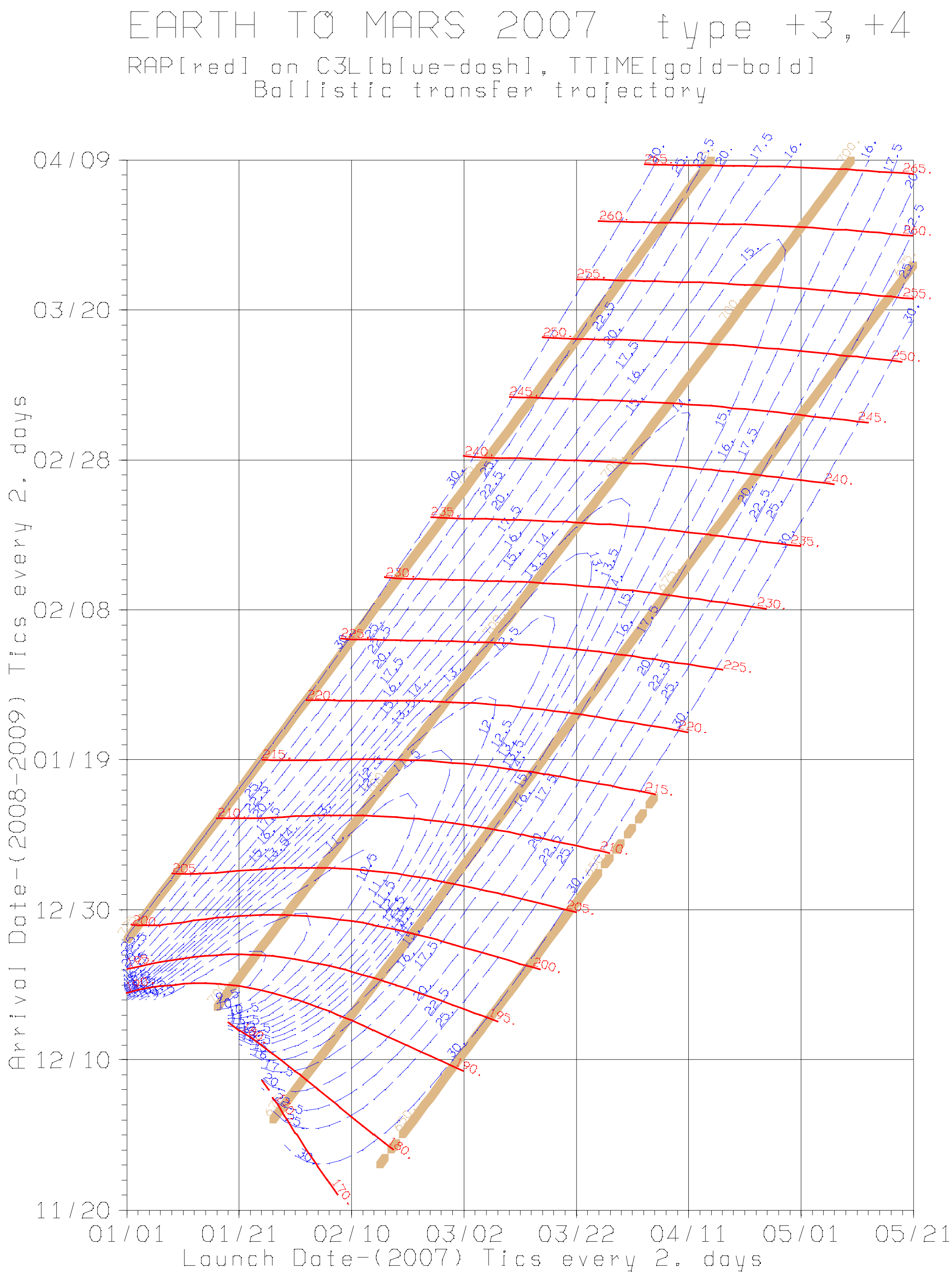


Figure 19: Right ascension of arrival asymptote (RAP) contours for the Type +III and +IV ballistic trajectories in 2007.

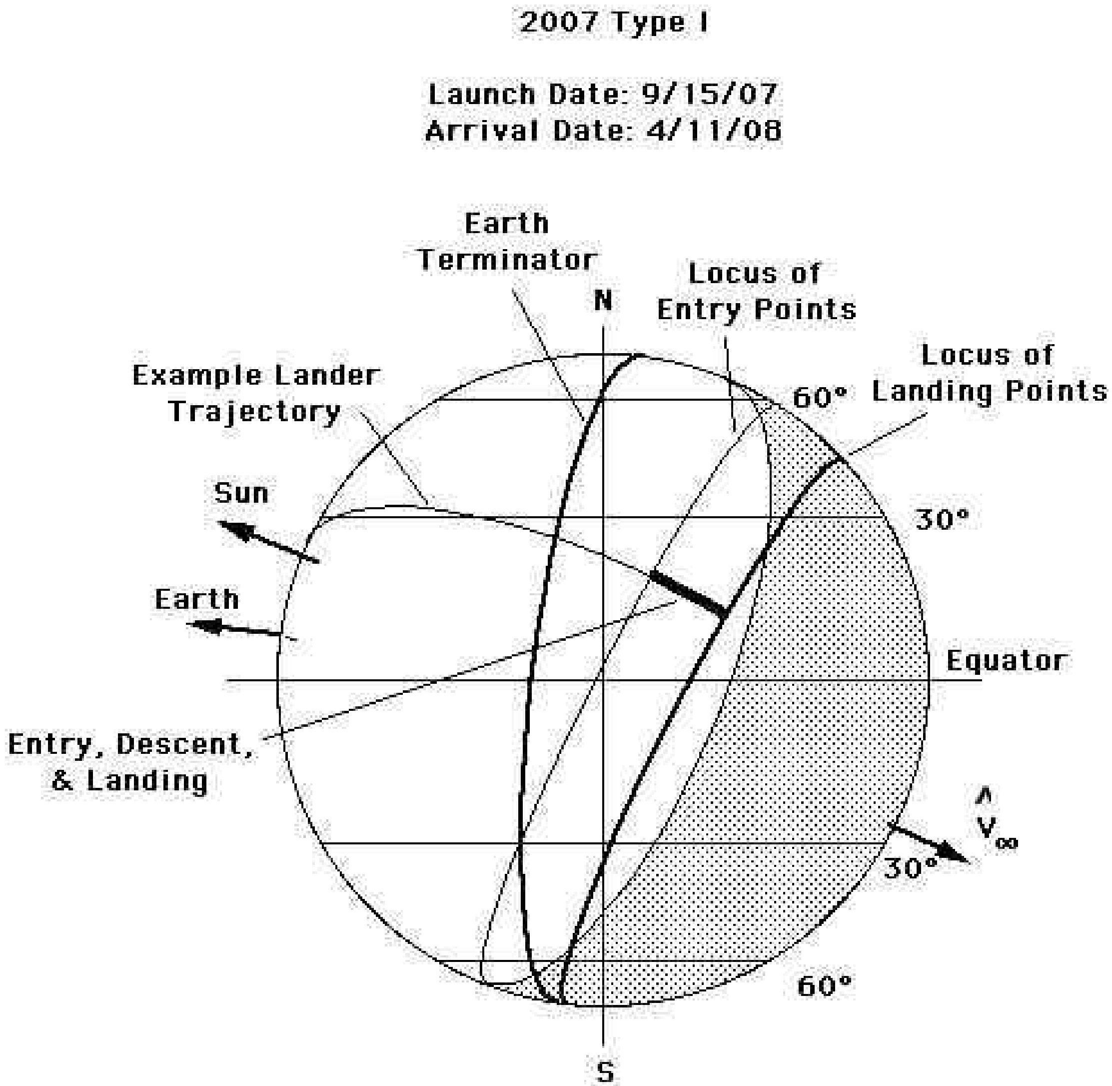


Figure 20: Arrival geometry for a representative Type I trajectory from Earth to Mars in 2007. Note that this graphic is a representation of the arrival geometry for a particular ballistic trajectory option with a specified launch and arrival date. It is meant to be representative only. If the launch and/or arrival date differs from those listed above, or if the selected trajectory is non-ballistic, this graphic will not necessarily apply and may result in erroneous conclusions.

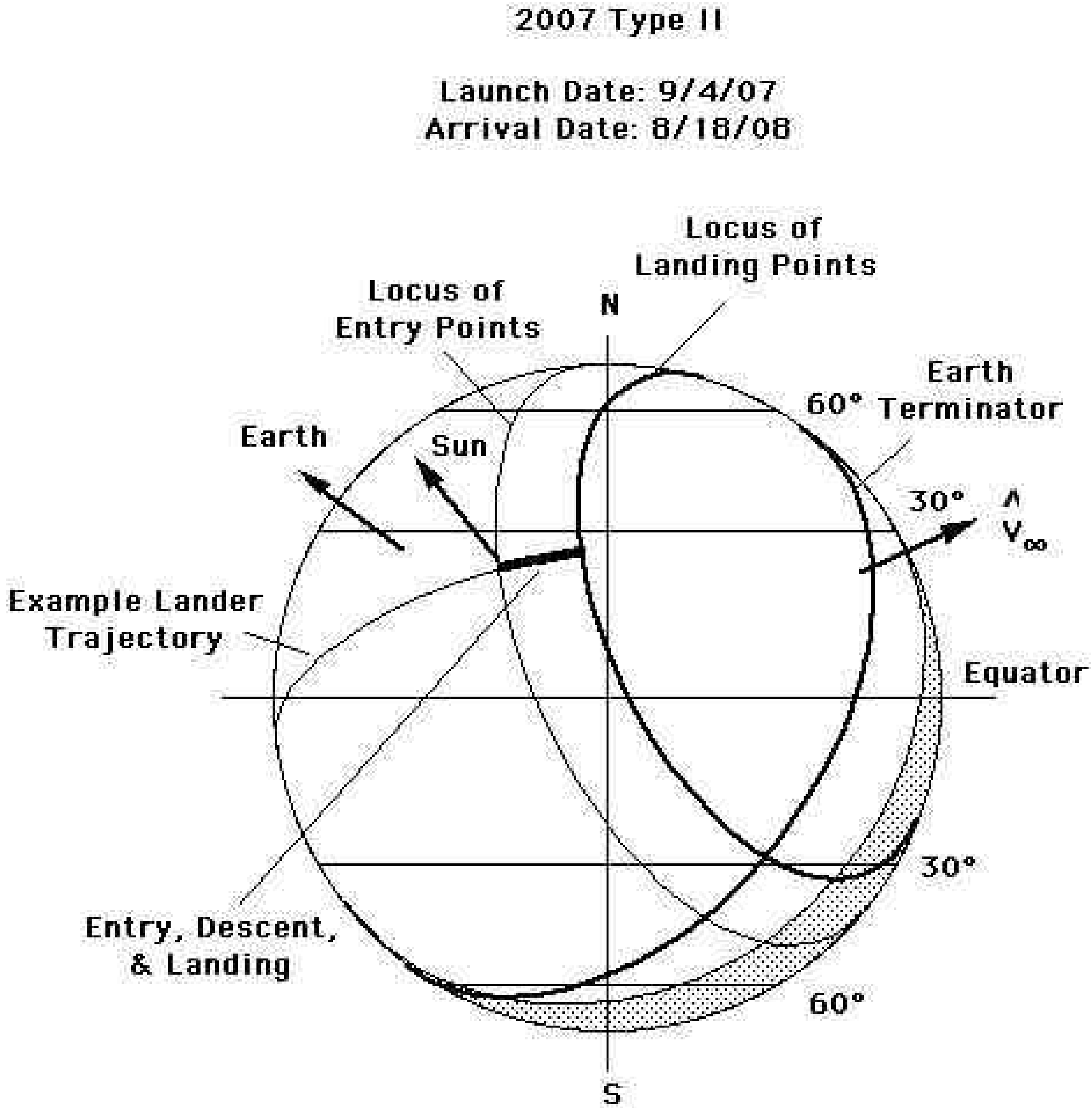


Figure 21: Arrival geometry for a representative Type II trajectory from Earth to Mars in 2007. Note that this graphic is a representation of the arrival geometry for a particular ballistic trajectory option with a specified launch and arrival date. It is meant to be representative only. If the launch and/or arrival date differs from those listed above, or if the selected trajectory is non-ballistic, this graphic will not necessarily apply and may result in erroneous conclusions.

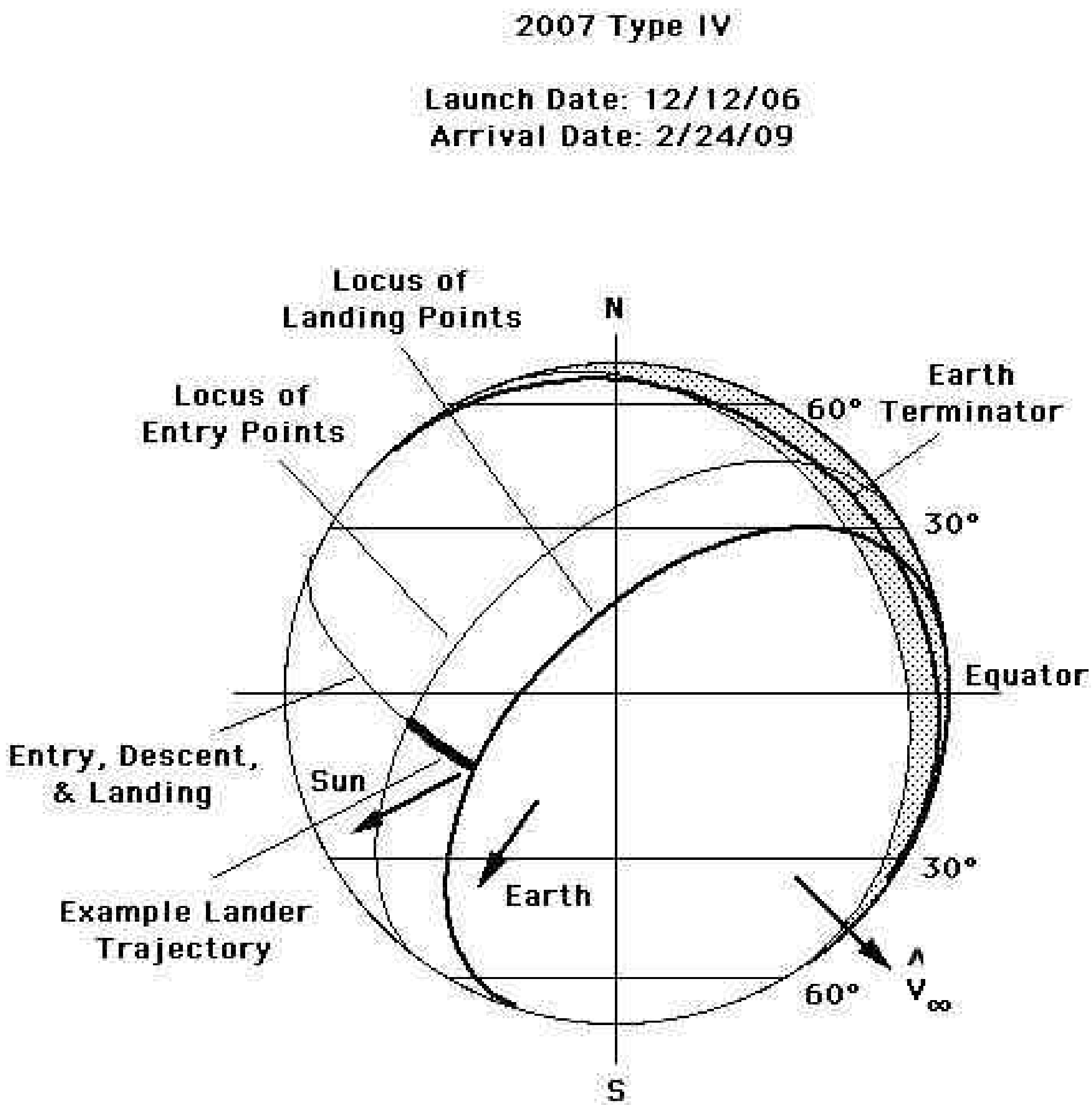


Figure 22: Arrival geometry for a representative Type IV trajectory from Earth to Mars in 2007. Note that this graphic is a representation of the arrival geometry for a particular ballistic trajectory option with a specified launch and arrival date. It is meant to be representative only. If the launch and/or arrival date differs from those listed above, or if the selected trajectory is non-ballistic, this graphic will not necessarily apply and may result in erroneous conclusions.

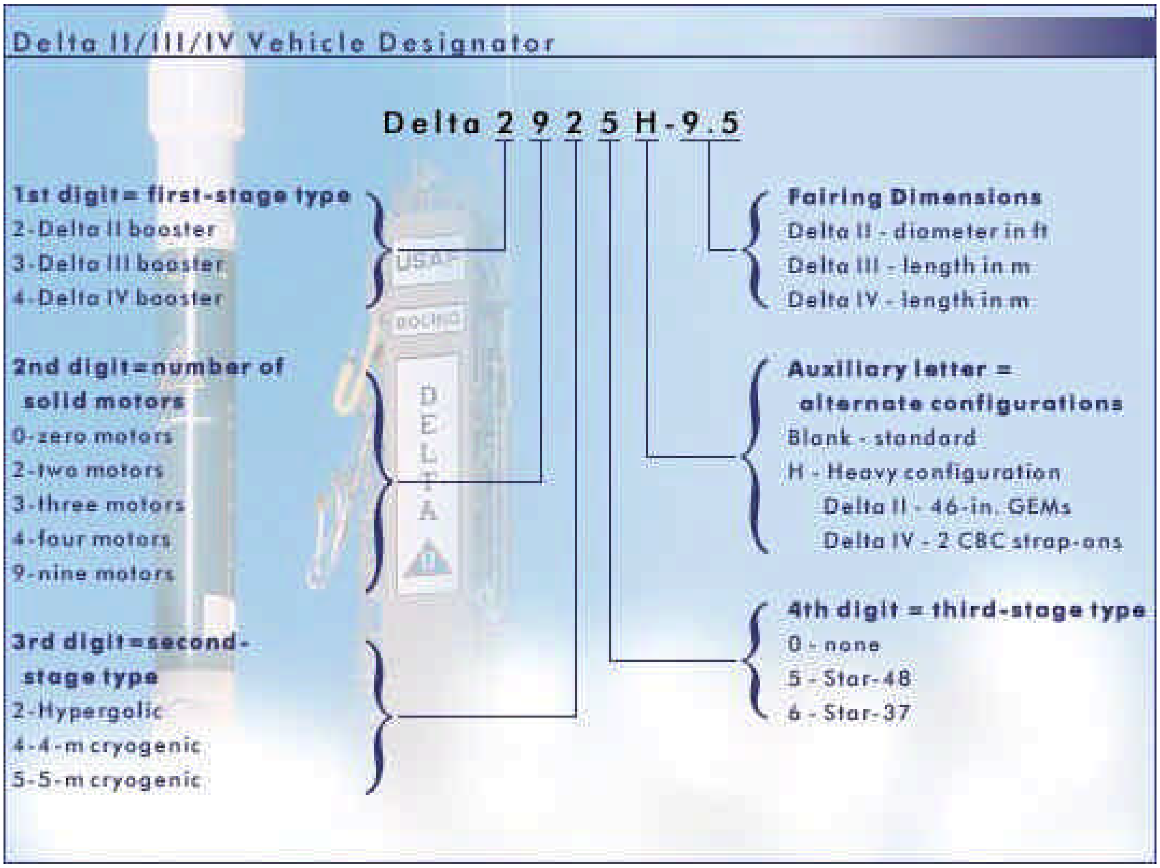


Figure 23: Naming/numbering convention for the Boeing Delta launch vehicle configuration.

Launch Vehicle Assumptions:

<u>Delta 2920-9.5</u>

- 6915 payload attach fitting (PAF)
- 99.7% Probability of Commanded Shutdown (PCS)
- 185 km park orbit altitude
- Low spacecraft mass will experience high acceleration
- 28.7 degree park orbit inclination

(Last updated 1/10/2001)

<u>Delta 2326-9.5</u>

- 3724 Payload Attach Fitting (PAF)
- 99.7 percent Probability of Commanded Shutdown (PCS)
- 185 km park orbit altitude
- low spacecraft mass will experience high acceleration
- 28.7 degree park orbit inclination
- Despin/NCS not included. If added, this is approximately a 25 kg reduction in performance.
- NCS mods may require significant increase in cost
- Missions with maximum spacecraft mass capabilities of 1495 - 1545 kg require stage 2 restarts shorter than the minimum guided burn and therefore entail slightly increased injection errors; alternatively, the minimum guided burn can be provided with reduced mass capability.

(Last updated February 14, 2001)

<u>Delta 2425-9.5</u>

- 3712A Payload Attach Fitting (PAF)
- 99.7 percent Probability of Commanded Shutdown (PCS)
- 185 km park orbit altitude
- low spacecraft mass will experience high acceleration
- 28.7 degree park orbit inclination
- offload required for C3's <= -4.1835 with 3 m Composite Fairing
- offload required for C3's <= -7.266 with 2.9 m Fairing
- spacecraft mass less than 680 kg may require NCS mods resulting in a decrease in spacecraft mass
- NCS mods may require significant increase in cost
- Missions with maximum spacecraft mass capabilities of 890 - 946 kg require stage 2 restarts shorter than the minimum guided burn and therefore entail slightly increased injection errors; alternatively, the minimum guided burn can be provided with reduced mass capability.

(Last updated February 14, 2001)

Figure 24 : Assumptions used for determining launch vehicle performance. If a mission violates any of these assumptions, the determined performance may not be accurate.

Delta 2925-9.5

- 3712A Payload Attach Fitting (PAF)
- 99.7 percent Probability of Commanded Shutdown (PCS)
- 185 km park orbit altitude
- low spacecraft mass will experience high acceleration
- 28.7 degree park orbit inclination
- spacecraft mass less than 680 kg may require NCS mods resulting in a decrease in spacecraft mass
- NCS mods may require significant increase in cost
- Missions with maximum spacecraft mass capabilities of 2810 - 2894 kg require stage 2 restarts shorter than the minimum guided burn and therefore entail slightly increased injection errors; alternatively, the minimum guided burn can be provided with reduced mass capability.

(Last updated February 14, 2001)

Delta 2925H-9.5

- 3712A Payload Attach Fitting (PAF)
- 99.7 percent Probability of Commanded Shutdown (PCS)
- 185 km park orbit altitude
- low spacecraft mass will experience high acceleration
- 28.7 degree park orbit inclination
- spacecraft mass less than 680 kg may require NCS mods resulting in a decrease in spacecraft mass
- NCS mods may require significant increase in cost
- configuration has not yet flown and may require significant increase in cost
- Missions with maximum spacecraft mass capabilities of 3811 - 3912 kg require stage 2 restarts shorter than the minimum guided burn and therefore entail slightly increased injection errors; alternatively, the minimum guided burncan be provided with reduced mass capability.

(Last updated February 14, 2001)

Mission Unique Contingencies:

The following data represents an estimate as to reduced launch vehicle performance for a particular mission unique item:

Dual daily launch opportunities:	-1%
Nuclear Safe Parking Orbit:	-5% to –10%
Large PLF Doors (5m fairing):	-15 kg to –20 kg
High Declination (|DLA| up to 40 deg.):	-5%

Figure 24 (Continued): Assumptions used for determining launch vehicle performance. If a mission violates any of these assumptions, the determined performance may not be accurate

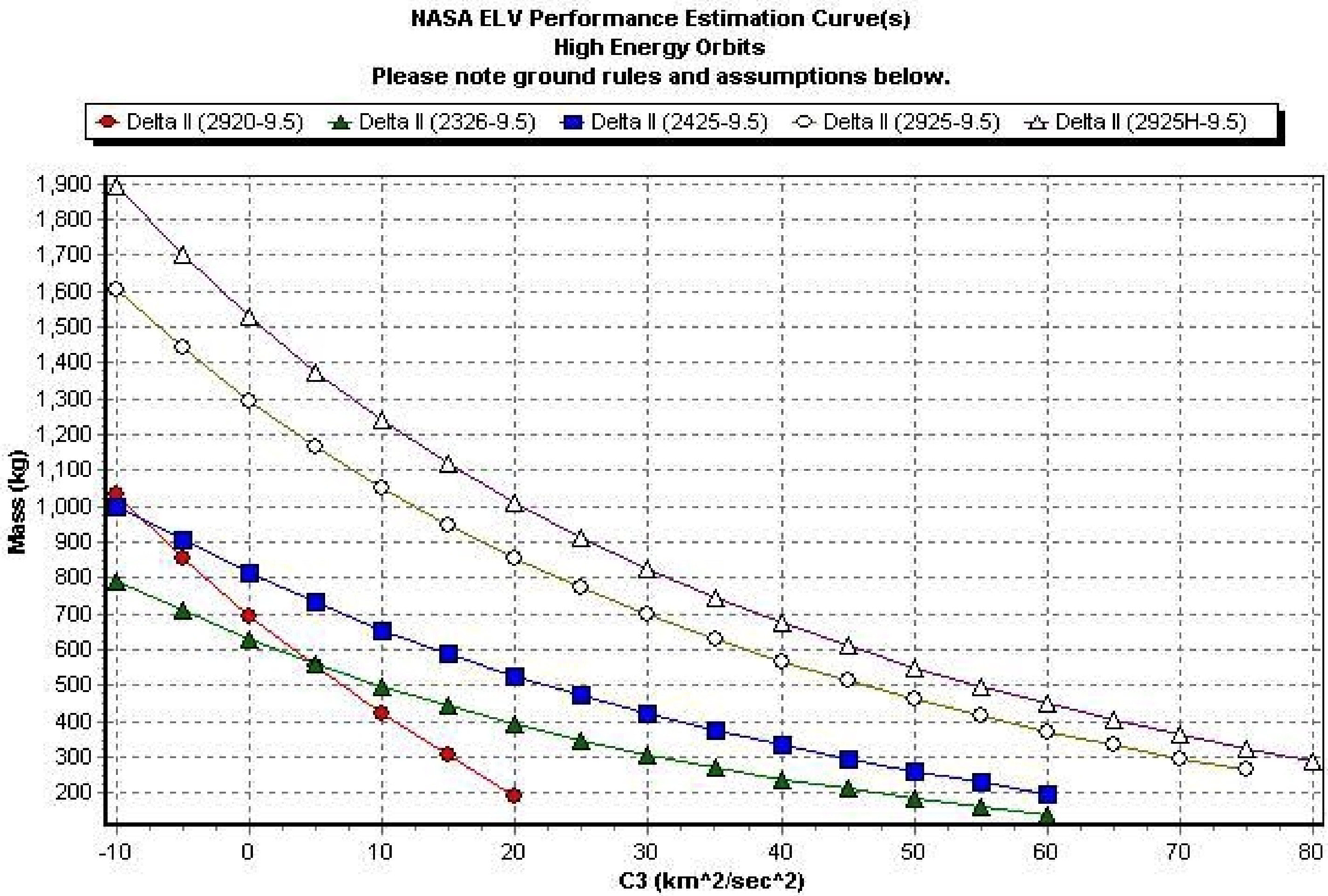


Figure 25: Launch vehicle performance for several Boeing Delta configurations. This data is provided by NASA Kennedy Space Center and reflects the current best estimate data. Please refer to **Figure 24** for a list of assumptions used to generate this data. Any mission unique contigencies should be subtracted from the performance provided here.

2007 SEP MARS LAUNCH OPPORTUNITIES

(All results are estimates; to be used for planning purposes ONLY!)

LANDER (1.0y TOF)	Launch vehicle	Delta 2925-9.5
	Number of engines	1
	Solar array power (kW)	5
	Optimum launch date	29-Aug-07
	Launch C3 (km^2/s^2)	6.7
	Declination of launch asymptote (deg)	16.9
	Arrival date at Mars	28-Aug-07
	Arrival V (km/s)	1.9
	Declination of arrival asymptote (deg)	12.9
	Rt. Ascension of arrival asymptote (deg)	206.2
	Total Injected mass (kg)	1127
	Estimated SEP stage mass (kg - dry)	285
	Xe propellent mass (kg)	52
	Associated "host" spacecraft mass (kg)	790
ORBITER (1.3y TOF)	Launch vehicle	Delta 2925-9.5
	Number of engines	2
	Solar array power (kW)	10
	Optimum launch date	26-Jul-07
	Launch C3 (km^2/s^2)	2.2
	Declination of launch asymptote (deg)	11.2
	Arrival date at Mars (end of spiral)	10-Jun-09
	Spiral in time (days)	210
	Total Injected mass (kg)	1235
	Estimated SEP stage mass (kg - dry)	365
	Xe propellent mass (kg)	257
	Associated "host" spacecraft mass (kg)	613

Assumptions:

¥˚There is an infinite option space with respect to Solar Electric Propulsion (SEP) trajectories; these options are affected by such things as launch vehicle, solar array power, number of thrusters, flight time, etc. The options provided here are meant

¥ Results found by optimizing launch date for a fixed time of flight; estimated cost for 20 day launch period:B33 ~1-2% injected mass (–~1 km^2/s^2 C3 and –~1-2 deg DLA).

¥˚NSTAR engine Q; Advanced Si solar array power provided for 1 AU EOM (no degredation assumed); 90% duty cycle; 400W spacecraft power.

¥˚SEPTOP launch vehicle performance approximates current NLS data, with the exception of all Delta II vehicles where KSC current best estimate performance data is used.

¥˚The SEP stage mass is based on CNSR CBE's and approximations (no uncertainty included); includes estimate on structure mass to accomodate launch loads for "host" spacecraft.

¥˚500 km altitude circular orbit assumed for spiral in/out final/initial orbit at Mars; arrival C3 at Mars is ~0 km^2/s^2 therefore, any orbit inclination should be achievable with minimal costs.

¥ Delta II launch vehicle performance data reflects current best estimates from KSC (see assumptions provided with launch vehicle data).

Figure 26: Representative Solar Electric Propulsion (SEP) trajectories from Earth to Mars in 2007.

Exhibit IV - Mars Program Infrastructure; Preliminary Assumptions (subject to change)

Telecommunications/Navigation Relay Orbiters with Relay assets:

• 2005 Mars Reconnaissance Orbiter (MRO)

Relay support will be available beginning in May 2008, however, this support may be limited due to the continuing MRO primary science mission. Full relay support will be available beginning in January 2009.

The MRO orbit will be near-circular at 400 km altitude and 92.9° inclination (3pm sun-synchronous). This results in a maximum slant range to the orbiter at minimum elevation (15°) of about 1030 km. The MRO is assumed to have a UHF antenna with a –0.2 dBi gain (nadir pointed – 3 dB) at minimum elevation. (See Figure 27 at the end of this Exhibit)

• 2007 ASI Telecommunications/Navigation Orbiter (ASI Telesat)

Relay support will be available beginning in September 2008. (Support may be available as early as mid-August 2008 depending upon arrival date and duration of spacecraft checkout, etc.)

The ASI Telesat orbit will be circular at 4450 km altitude and 130.2° inclination (terminator sun-synchronous). This results in a maximum slant range to the orbiter at minimum elevation (15°) of about 6250 km. The ASI Telesat is assumed to have a UHF antenna with a 7.4 dBi gain (nadir pointed – 3 dB) at minimum elevation. (See Figure 27 at the end of this Exhibit)

• CNES Netlander Orbiter

Relay support will be available beginning in September 2008 through August 2010 (arrival plus 1 Martian year), however, this support may be limited due to the Netlander mission relay requirements. Availability may be increased after a minimum 90 sol Netlander mission. Relay support beyond August 2010 is uncertain due to an undefined extended mission for this orbiter.

The orbit will be circular at 1000 km altitude and 94.9° inclination . This results in a maximum slant range to the orbiter at minimum elevation (15°) of about 2050 km. The CNES orbiter is assumed to have a UHF antenna with a 1.6 dBi gain (nadir pointed – 3 dB) at minimum elevation. (See Figure 26 at the end of this Exhibit)

DSN Resource Assumptions:

• Use only 34 meter assets for nominal operations; 70 meter antennas available only for emergency operations.

• For a representative description of mission operations services, refer to NASA's Mission Operations and Communications Services document provided for the Pluto-Kuiper Belt Mission Announcement of Opportunity (AO: 01-OSS-01) which can be found at:

http://centauri.larc.nasa.gov/pluto/NASA_Miss_Ops_Comm.pdf

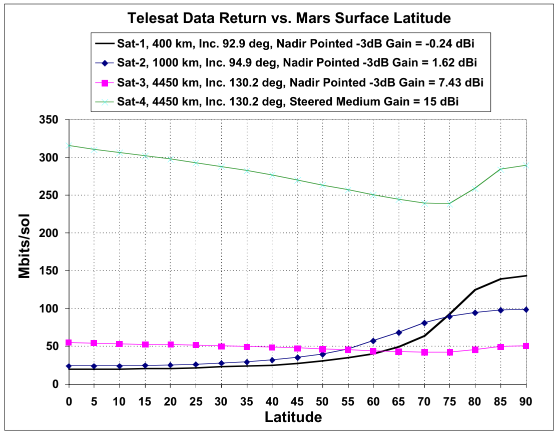
Navigation Performance Assumptions:

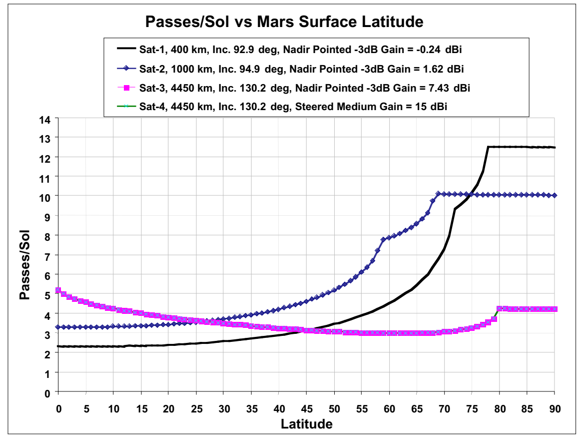
Stationary Mars surface elements can assume 30m (3σ) position determination. This position determination assumes the surface element has two-way UHF Doppler capability to one Mars telecommunication / navigation orbiter and several communications passes over a few days occur.

Summary Comparison of Various Orbit Alternatives

Mars Reconnaissance Orbiter
CNES Netlander Orbiter
ASI Telesat with Nadir Pointed Ant.
ASI Telesat with Steered Ant.

	Active (1=on, 0=off)	Orbit Altitude (km)	Orbit Inclination (deg)	S/C Antenna Gain at min elev (dBi)	Min Elev (deg)	Kbits Per Joule at 15 deg Elev	Max Slant Range at 15 deg Elev, (km)	Data Rate at Ref Power and Range, (kbps)
SAT1	1	400	92.9	-0.2	15	19.6	1031.5	19.6
SAT2	0	1000	94.9	1.6	15	7.6	2047.8	7.6
SAT3	0	4450	130.2	7.4	15	3.1	6248.9	3.1
SAT4	0	4450	130.2	15.0	15	17.8	6248.9	17.8

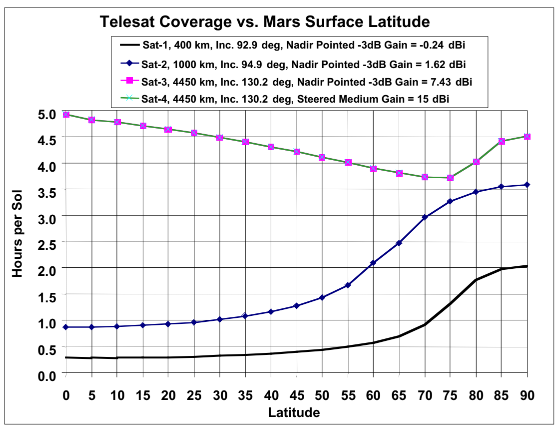


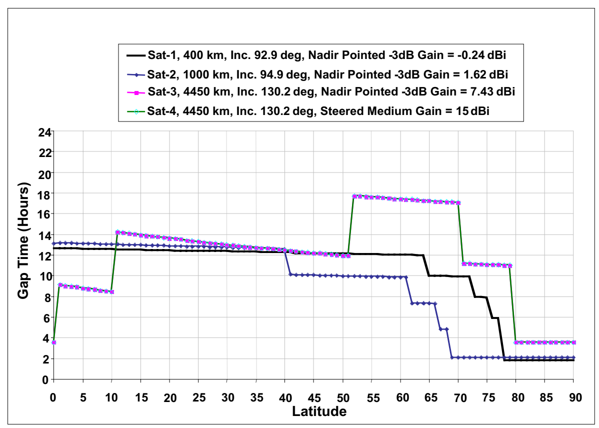


Notes:

Data Rates Numbers Assume

1) 1 Watt Omni to Indicated S/C antenna
2) Range at 15 deg elev angle
3) 3 dB Operating Margin





To Scale Results

1) Scale Rates and Volume Directly with respect to your spacecraft EIRP vs. reference 0 dBW EIRP
2) Scale Rates and Volume Directly with respect to your S/C antenna gain vs. reference S/C Antenna gain
3) Scale Rates and Volume inversely with respect to your max range squared vs. reference max range squared

Figure 27: Mars Telecommunications Infrastructure Orbiting Assets: representative (reflects a current design concept; the final design is not yet available) orbit description, performance/capability, and lattitude coverage for the 2005 NASA Mars Reconnaissance Orbiter (MRO), the 2007 CNES (Centre National d Etudies Spatiales — the French Space Agency) Netlander Orbiter, and the 2007 ASI (Agenzia Spaziale Italiana — the Italian Space Agency) Telesat Orbiter (fixed and steerable antenna option provided).

EXHIBIT V

SCIENTIFIC GOALS, OBJECTIVES, INVESTIGATIONS, AND PRIORITIES

Mars Exploration Program / Payload Analysis Group

Edited by R. Greeley, 2 March 2001

This document is the result of a series of meetings and workshops (Table 1) collectively involving more than 110 individuals from the Mars community with representatives from universities, research centers and organizations, industry, and international partners for Mars exploration. Although the effort was focused through activities of the Mars Exploration Program/Payload Analysis Group (MEPAG, chaired by R. Greeley), participation has been much wider, as indicated in Appendices 1-4, and builds on the work of the Mars Exploration Science Group led by D. McCleese.

Initial discussions and earlier drafts of this document were centered on Mars Program goals related to Life, Climate, and Resources, with the cross-cutting theme of follow the water. It generally has been recognized that geological sciences and investigations which would lead to exploration by humans were incorporated in the Resources goal. The consensus reached in August 2000 was that the program goals should be recast as Life, Climate, Geology, and Preparation (for Human Exploration), with water remaining a cross-cutting theme.

Table 1. **Meetings and workshops used to develop the scientific goals objectives, investigations and measurements for Mars exploration.**

Group	Date	# of participants
MAST	11-12 Jan. 2000	5
MEPAG/MPRG	22-24 Feb. 2000	101
MAST	6 Jun. 2000	8
MAST	weekly/semi-monthly telecons	**3-6**
MEPAG	8-10 Aug. 2000	49
MAST	1 Nov. 2000	12
MEPAG	15-17 Nov. 2000	65

MAST (*Mars Ad hoc Science Team)*
MEPAG *(Mars Exploration Program/Payload Analysis group)*
MPRG (*Mars Peer Review Group;* one-time meeting)

The objectives, investigations, and measurements needed for the exploration of Mars have been formulated and prioritized by subgroups of participants focused on the four principal exploration goals. Individuals were free to participate in more than one group during workshops and there were intergroup critiques of the objectives, investigations, and measurements the results of which are reflected here.

Within each objective, the investigations are listed in priority order as determined within each discipline. There was no attempt to synthesize the overall set of investigations, but it was recognized that synergy among the various goals and objectives could alter the priorities in an overall strategy. Completion of all the investigations will require decades of effort. It is recognized that many investigations will never be truly complete (even if they have a high priority) and that evaluations of missions should be based on how well the investigations are addressed. While priorities should influence the sequence in which the investigations are conducted, it is not intended that they be done serially, as many other factors come into play in the overall Mars Program. An evaluation of the technology development needed to conduct each measurement is given as "none," "some," or "much."

I. GOAL: DETERMINE IF LIFE EVER AROSE ON MARS

Objectives A and B are regarded as co-priorities and should be addressed in parallel. Although the investigations and measurements within these objectives are generally ordered by progression from orbital science to surface exploration to sample return, orbital missions should be interleaved synergistically with in situ science and sample return to optimize selection of landing sites and samples for study.

A. Objective: Determine if life exists today.

1. Investigation*:* Map the 3-dimensional distribution of water in all its forms. Zones of liquid water in the subsurface provide the most likely environments for extant life on Mars. In the absence of life, such environments could also sustain pre-biotic chemistry of interest for understanding the origin of life on Earth. **Requires global remote sensing of water in all its forms to identify the locations, phases, and, if possible, temporal (seasonal) changes in near-surface water budgets.**

Measurements

a) Global search and mapping of water to 10 km depth at a horizontal spatial resolution of 100 m and a vertical resolution of 10 m for the upper 500 meters and a few hundred meters below that depth; must be able to distinguish CO2 clathrate, ice and liquid water. *Technology development needed: Modest*.

2. Investigation: **Carry out in situ exploration of areas suspected of harboring liquid water.** Results will be used to validate remote sensing observations and to explore for life or prebiotic chemistry. **Requires subsurface drilling, in situ instrumentation to detect water in all its forms (inclusive of microenvironments; e.g. brine films), CO2 clathrate and to analyze rocks, soils and ices for organic compounds or to detect life.**

Measurements

a) For at least 20 stations at 4 targeted sites (based on remote sensing), conduct in situ geophysical and chemical (e.g. "sniffers") searches for subsurface water and other volatiles (e.g. carbon dioxide and reduced gases like methane and ammonia) over km2 surface areas. *Technology development needed: Some.*

Note: The following two investigations (b and c) could be done in parallel.

b) For at least 3 targeted sites, drill initially to 2 meters depth and later to 100s of meters and conduct experiments to detect thin films (~50 um) of water and major and trace volatiles in ices (e.g., carbon dioxide reduced gases such as methane and ammonia) in surface and subsurface soils and atmospheric measurements of trace gases. *Technology development needed: much* (subsurface drilling).

c) For at least 3 targeted sites, drill initially to 2 meters depth and later to 100s of meters and search for biogenic elements (e.g., C, H, N, O, P and S) and their oxidation states, organic compounds (e.g., amino acids, proteins, carbohydrates, lipids, nucleic acids, etc.) and chirality. *Technology development needed: Much* (subsurface drilling to 10 m and deeper; in situ detection of organics).

***3. Investigation*: Explore high priority candidate sites (i.e., those that provide access to near-surface liquid water) for evidence of extant (active or dormant) life forms**. Although the means for in situ life detection is poorly defined, basic measurements are likely to include both in situ analysis and laboratory-based analysis of pristine (uncontaminated or unaltered) samples to search for organic and inorganic biosignatures, metabolic activity, isotopic fractionation, disequilibrium chemistry, etc. **Requires in situ life detection experiments on subsurface materials and laboratory analysis of returned core samples.**

Measurements

Note: 3a. could be done in conjunction with 2b&c.

a) In situ experiments for at least three targeted sites to detect extant or dormant life in soils and ices; could include the search for complex organic compounds at a ppb detection limit (e.g. amino acids, proteins, carbohydrates, lipids, nucleic acids, etc.), chirality, fluorescent staining and microscopy for specific biomolecules, metabolic products, methods for nucleic acid amplification, and potentially, culture-based methods to detect growth and metabolism, etc. Methods should include a means for the detection of false positives (i.e., for assessing forward contamination). *Technology development needed: Much*.

b) Sample return (.5 - 1.0 kg each from 3 diverse sites) for laboratory-based life detection experiments, such as advanced GC-MS analysis of powdered rocks, microscopy (e.g. light, fluorescent and laser confocal, TEM, SEM, X-ray tomography, laser Raman imaging, etc.) of rock surfaces and interiors to explore for chemical (isotopic, trace elemental, etc.), morphological and mineralogical biosignatures and methods to search for metabolic activity, disequilibrium chemistry, etc. *Technology development needed: Modest* for measurement technologies; much for sample containment assurance.

***4. Investigation:* Determine the array of potential energy sources available on Mars to sustain biological processes.** Biological systems require energy that could come from a variety of sources and use a wide variety of transudation mechanisms. Potential sources include chemical redox, pH gradients, geothermal heat, radioactivity and incident radiation (sunlight). Requires orbital mapping, in situ investigations and sample return.

Measurements

a) Remote sensing to map biogenic elements (e.g. C, H, N, O, P, and S) and their oxidation states, transition metals, and aqueous minerals [including carbonates, fixed inorganic nitrogen, phosphates, sulfates, halides, metallic oxides (e.g. hematite) and sulfides, clays, etc.]. Need coverage at all high priority sites (5% of planet's surface) that show geomorphic evidence for prolonged hydrological activity. Local coverage of all high priority sites at a minimum spatial resolution of 100 m (mineral mapping) and a few km (for elemental mapping) at a spectral resolution of 2.5 nm over the range1.0-5.0 microns. Technology development needed: Some for halides and metal oxides; Much for elements.

b) Thermal infrared remote sensing to search for local geothermal "hot-spots" in the shallow crust at a spatial resolution of 100 m. *Technology development needed: none*.

c) Remote sensing to search for point-source concentrations of volatiles (e.g. gas-emitting vents, or "fumeroles") using near and mid-IR spectroscopy at a spatial resolution a few km. *Technology development needed: some*.

d) In situ investigations to search for biogenic elements (e.g. C, H, N, O, P, and S) and their oxidation states, transition metals, and aqueous minerals [including carbonates, fixed inorganic nitrogen, phosphates, sulfates, halides, metallic oxides (e.g. hematite) and sulfides, clays, etc.] and evidence of chemical disequilibrium, including gradients and redox chemistry, pH, temperature, radiation, etc. *Technology development needed: Modest*.

e) In situ investigations to explore for specific classes of organic molecules (derivatives of chromophores, including porphyrins and their precursors, pyroles) which are known to be important for energy-transduction in living systems on Earth. *Technology development needed: Modest*.

f) Returned samples (minimum of 0.5 - 1.0 kg from each of 3 diverse sites) for mineralogical and geochemical characterization (potential analyses include X-ray diffraction, X-ray tomography, X-ray fluorescence, ICP-MS, etc). *Technology development needed: much*.

5. Investigation*:* **Determine the nature and inventory of organic carbon in representative soils and ices of the Martian crust**. Carbon is a fundamental building block for life. It may exist within soils and ices in a variety of biotic and abiotic forms. Its distribution would exert a primary control on where and how life could develop. **Requires in situ exploration and sample return**.

Measurements

a) In situ analysis of surface and subsurface (to a few meters depth) soils and ices to search for organic compounds (e.g., amino acids, proteins, carbohydrates, lipids, nucleic acids, etc.)

and their concentration gradients, and to detect seasonal fluxes in carbon dioxide and reduced gases (e.g. methane, ammonia, etc.). *Technology development needed: much* (in situ organics detection; Much for subsurface drilling).

b) Returned samples (0.5-1.0 kg from each of 3 diverse sites) to analyze soil and rock cores for organic compounds, including molecular structures, stable isotope compositions (e.g. C, H, N, O, P and S) and their oxidation states. Must also apply methods for assessing sample containment assurance and for detecting false positives (i.e., forward contamination). *Technology development needed: much*.

6. Investigation: **Determine the distribution of oxidants and their correlation with organics.** Results from Viking suggest that unknown oxidation processes in Martian soils are responsible for the selective destruction of organic compounds. The distribution of oxidants on Mars is likely to have been a controlling factor in determining where, when and how life might have developed. **Requires instrumentation for determining the elemental chemistry and mineralogy of surface and subsurface samples**.

Measurements

a) In situ experiments at one well-targeted low latitude site and 1.0 meter depth to determine gradients in the concentration of electrochemically active species (e.g. oxygen and hydrogen) at ppm concentrations and susceptibility of metallic and organic compounds to oxidation and to determine the spatial and depth distribution of specific classes of oxidizing compounds (e.g., peroxides, etc.). *Technology development needed: Modest*.

B. Objective: Determine if life existed on Mars in the past.

1. Investigation: **Determine the locations of sedimentary deposits formed by ancient and recent surface and subsurface hydrological processes**. Such deposits provide the best repositories for preserving a fossil record of ancient Martian life. **Requires global mapping of geomorphology and mineralogy, followed by in situ "ground truth" of mineralogy and geochemistry for remote sensing and to assist the selection of landing sites and samples for return to Earth**.

Measurements

a) Global remote sensing in the visible at 15 m spatial resolution to search for geomorphic features (e.g. paleolake basin shoreline deposits, fluvial-deltaic deposits, hydrothermal spring mounds, etc.) indicative of aqueous sedimentary processes. *Technology development needed: none*.

b) Global mapping in the mid-IR (wavelength range: 5-14 um) at 100 m resolution; targeted at 40 m spatial resolution hyperspectral mapping (1-5 um, 2.5 nm spectral resolution of aqueous sedimentary deposits (e.g., those targeted at lower resolution based on geomorphic and mineralogical evidence for prolonged aqueous sedimentary processes) to explore for aqueous mineralogies (e.g., carbonates, fixed inorganic nitrogen, phosphate, silica, metallic oxides (e.g. hematite) and sulfides, sulfates, borates, halides, clays, etc.) that are potential repositories for fossil biosignatures. High spatial resolution mapping (100 m) in thermal IR to explore for near surface hydrothermal systems. Technology development needed: Some.

c) In situ measurements (e.g. laser Raman, infrared spectroscopy, X-ray diffraction,/X-ray fluorescence, etc.) to determine the mineralogy and geochemistry of potential aqueous materials, such as carbonates, fixed inorganic nitrogen, phosphates, silica, sulfates, halides, borates, metallic oxides, (e.g. hematite) and sulfides, clays, etc., including hydrous weathering products formed by interactions of primary lithologies with water, conducted at a minimum of 3 diverse sites for obtaining ground truth to calibrate orbital IR measurements. Technology development needed: Modest.

2. Investigation: **Search for Martian fossils (morphological and chemical biosignatures of ancient life).** Life can leave a variety of bio-signatures in water-deposited rocks. Based on studies of the fossil record on Earth, certain environments and types of deposits provide favorable settings for the preservation of fossil biosignatures. These include environments where fine-grained, clay-rich deposits form in lakes and streams, or where minerals precipitate rapidly from water in the presence of organisms. Locating the most favorable deposits for preserving fossil biosignatures requires remote sensing, in situ analysis, and targeted sample returns.

Measurements

a) Global remote sensing at 15 m spatial resolution in the visible to search for geomorphic features (e.g. paleolake basin and shoreline deposits, fluvial-deltaic deposits, hydrothermal spring mounds, etc.) and in the mid- and near-IR to explore for minerals (e.g. carbonates, fixed inorganic nitrogen, phosphates, silica, sulfates, halides, borates, metallic oxides (e.g. hematite) and sulfides, clays, etc.) indicative of aqueous sedimentary processes. *Technology development needed: some*.

b) In situ analyses of aqueous sedimentary lithologies (e.g. using laser Raman spectroscopy, infrared-spectroscopy, X-ray diffraction/fluorescence, etc.) conducted at a minimum of 3 well-characterized and diverse sites to determine the mineralogies (e.g. aqueous minerals, reduced phases, biominerals, etc.), macro- and micro-scale rock textures and carbon compounds (e.g. total carbon content, the presence of particulate kerogen or more volatile hydrocarbons, etc.) in aqueous sediments (e.g. siliciclastics, carbonates, evaporites, etc.) and to explore for potential biosignatures (e.g. chemofossils, biosedimentary structures, etc.) preserved in sedimentary rocks. Technology development needed (some).

c) Return of targeted samples (0.5-1.0 kg) from each of 3 sites "certified" to be of aqueous sedimentary origin) for detailed microscopic (e.g., light, fluorescence and laser confocal microscopy, TEM, SEM, X-ray tomography, laser Raman imaging, etc.), geochemical analysis (e.g. isotopic, trace element), mineralogical characterization (e.g. using laser Raman mapping spectroscopy, X-ray diffraction-X-ray fluorescence, etc.), and organic analysis (e.g. gas chromatography-mass spectrometry; laser desorption spectroscopy, etc.) and to search for fossil biosignatures (e.g., organic-walled microfossils or their mineralized replacements, chemofossils (e.g., organic biomarker compounds, isotopic and trace element signatures) and biominerals). *Technology development needed: much* (sample return); Modest (instrumentation)

3. Investigation: **Determine the timing and duration of hydrologic activity.** To assess the potential for the origin and evolution of life on Mars during the planet's history, knowledge is needed for when, where, and how long liquid water environments were present at the surface and in the subsurface. This requires the development of stratigraphic (age) frameworks for deposits based on remote sensing, in situ measurements, returned samples from key sites for radiometric.

Measurements

a) In situ (using mobile platforms and subsurface drills) exploration for aqueous minerals [e.g. carbonates, fixed inorganic nitrogen, phosphates, silica, metallic oxides (e.g. hematite) and sulfides, sulfates, borates, halides, clays, etc.], water-formed geomorphic features (e.g. paleolake basin and shoreline deposits, fluvial-deltaic deposits, hydrothermal spring mounds, etc.) and diagnostic meso-scale sedimentary structures (e.g. planar cross bedding, oscillation ripples, mudcracks, teepee structures, various biogenic sedimentary structures, etc.) indicative of hydrologic activity. These detailed investigations should be conducted for at least 6 diverse units. *Technology development needed: Modest (rover development); None (instrumentation); Much (preparing for human exploration).*

b) Returned samples from at least 6 units suitable for establishing valid radiometric dates to calibrate the geologic time scale for Mars. Integrated petrographic and geochemical analyses for understanding initial isotopic ratios and the effects of shock metamorphism and weathering processes on the reliability of age dates. Note: Sampling strategies could include sites where diverse lithologies and units could be sampled at a single site. If overlapped with human exploration, initial sample analysis might be done at Mars. *Technology development needed: Modest (rover development); None (instrumentation); Much (preparing for human exploration).*

C. Objective: Assess the extent of prebiotic organic chemical evolution.

1. Investigation: **Search for complex organic molecules in rocks and soils**. The steps in pre-biotic chemistry that lead to life on Earth is unknown. On Earth, the record of those early events has been largely destroyed by plate tectonics and weathering. If life arose on Mars, it probably would have consumed and transformed much of the original organic inventory present. However, if life did not arise, the record of pre-biotic chemistry that developed in an Earth-like setting on early Mars is considered fundamentally important for developing the understanding of the chemical steps that preceded the appearance of life on Earth. Because Mars apparently lacks plate tectonics, it might provide an unrivaled record of early pre-biotic chemical events in an Earth-like setting. The exploration for pre-biotic chemistry ultimately requires a different approach than the search for the extant biochemistry. The search for pre-biotic chemistry requires studies of modern aqueous environments (e.g. groundwater, ice-brine transitions, hydrothermal systems, etc.) and the record of aqueous paleoenvironments preserved in ancient sedimentary rocks. Targets for in situ studies must be first identified by remote sensing based on geomorphology and mineralogy (see I.A.1) and then mobile platforms (rovers) used to determine mineralogy, geochemistry, organic chemistry, and returned samples.

Measurements

a) In situ/mobile platforms deployed to at least 3 well-characterized and diverse sites to assess the mineralogy (e.g. using laser Raman mapping spectroscopy, X-ray diffraction-X-ray fluorescence, etc.), geochemistry (e.g. alpha proton or mass spectrometer methods for elemental and isotopic compositions) and organic materials (e.g. gas chromatography-mass spectrometry; laser desorption spectroscopy, etc.). *Technology development needed: Modest* Rover development); Some (in situ instrumentation).

b) Return samples from at least 6 units suitable for radiometric dating to calibrate the geologic time scale of Mars. Integrated petrographic and geochemical analyses for understanding initial isotopic ratios and the effects of shock metamorphism and weathering on age date reliability. Measurement of other volatile components (e.g., D/H) to calibrate volatile history. *Technology development needed: much* (Sample return); some (lab instrumentation).

2. Investigation**: Determine the changes in crustal and atmospheric inventories of carbon through time**. Changes in the atmospheric and crustal carbon inventories over geologic time would have greatly affected the pre-biotic chemistry and climate of the Martian surface and, hence, the potential for life to develop. The detailed history of the carbon cycle will require intensive sample analysis of a wide range of rock types and ages. This objective parallels investigation I.A.4. (determine the crustal inventory of carbon) but seeks to integrate that information over time. Thus, the objective is posed in a historical way that will require a stratigraphic (temporal) framework for sampling (established through detailed geological mapping from orbit), in situ drilling and samples returned to Earth for detailed chemical analysis of carbon compounds and radiometric dating of samples.

Measurements

a) Global remote sensing in the near-infrared at ~40 m spatial resolution to map mineralogy. *Technology development needed: Modest*.

b) Returned samples (0.5-1.0 kg) from at least 6 well-dated, temporally diverse sites for both organic and inorganic carbon analysis (e.g. ratios of carbon isotopes, simple inorganic (e.g. bound volatiles like CO, CO2, CH4, etc.) and analysis of complex organic compounds (e.g. amino acids, proteins, carbohydrates, lipids, nucleic acids, etc.) preserved in rocks, soils and ices. *Technology development needed: much*.

c) Returned samples from at least 6 temporally-diverse units to establish radiometric dates to calibrate the geologic time scale. *Technology development needed: much*. (Note: In this context, technology (instrumentation) developments for precise in situ dating on Mars could mitigate the need for returned samples.

II. GOAL: DETERMINE CLIMATE ON MARS

A. Objective: Characterize Mars' present climate and climate processes (investigations in priority order)

***1. Investigation*: Determine the processes controlling the present distributions of water, carbon dioxide and dust.** Understanding the factors that control the annual variations of volatiles and dust is necessary to determine to what extent today's processes have controlled climate change in the past. **Requires global mapping and then landed observations on daily and seasonal time scales**.

***Measurements* (a, b and c concurrently)**

a) Global mapping with sufficient temporal resolution (define) to characterize seasonal variations of dust, water vapor, carbon dioxide and temperature requires daily global coverage of the planet with horizontal resolutions equal to, or better than, 5 degrees latitude and 30 degrees longitude. Some sampling of diurnal variations (e.g., day-night contrasts) is required to understand aliasing of longer term measurements. Water vapor, dust extinction and meteorological measurements taken concurrently (within one hour of one another). Vertical measurements are required with half-scale height resolution (< 5 km) over the following height ranges:

- Water vapor: 0-40 km with sensitivities of 3 % - 30% in mixing ratios over that range for reasonable water amounts (e.g., 5-10 precipitable microns column amounts)
- Dust and water ice cloud extinction: 0-60 km with ± 10% in extinction
- Temperature/Pressure: 0-80 km with typically 1-2 K precision and pressure registration to ± 1%
- Surface pressure: Required precision is a few percent for seasonal variations, < 1 % relative precision for dynamical (weather) variations
- Energy Balance: Albedo and thermal irradiance measurements adequate to compute surface net heat balance (and equivalent carbon dioxide flux) to ± 20% over representative regions of the permanent and seasonal polar caps.

Technology development needed: Modest.

b) Estimate water vapor flux, requiring in situ daily, diurnally resolved measurements of near-surface water vapor concentration over (latitudinally dependent) seasonal time scales (e.g., 60 sols in polar regions; 1 Mars year at non-polar latitudes). measurements needed at low, mid and high latitudes and in a variety of terrain (not necessarily concurrently): low and high thermal inertia regions, off and on the residual north polar cap. measurements from a site with subliming seasonal frost also desired. *Technology development needed: some*.

c) In situ measurements of adsorbed and solid water and carbon dioxide in the soil concurrent with the measurements described in a and b above to depths of a few cm at multiple times per day. Ice abundance measurements should cover the range from 0.01 to 1.0 g cm3 with 10% accuracy, Adsorbed H2O measurements should cover the range from 10-4 g/g to 10-2 g/g with 10% accuracy. measurements of adsorbed CO2 should cover the range from 10-5g/g to 10-3g/g with 20% accuracy. measurements adsorbed H2O and CO2 and water ice should also be conducted to depths of ~1 meter, but do not require diurnal or even seasonal temporal resolution. *Technology development needed: some*.

d) Detect near-surface (< 100 m) and deep (100 m – 5 km) liquid water; global mapping at scales of 10° longitude by 30° latitude. Determine depths to ± 10 m for near-surface water, ± 100 m at greater depth. *Technology development needed: much*.

e) Detect subsurface ice with precisions of 100-200 m as deep as 5 km, at horizontal scales of a few hundred kilometers. *Technology development needed: much*.

f) In situ meteorological measurements:

- Seasonal monitoring: Hourly measurements of temperature, pressure and atmospheric column dust opacity from 16 or more globally distributed sites for one Mars year
- Weather monitoring: Diurnally resolved (e.g., hourly) measurements of pressure, wind speed and direction, temperature, and optical depths from sites at high, middle and low latitudes, in both hemispheres, for a Mars year or longer. (At polar sites, winter measurements are not required, but are desirable.)
- Boundary layer processes: High frequency measurements (comparable to, or better than, 1 sec sampling) of near-surface wind, temperature and water vapor concentration for representative portions (~ 15 minute sampling intervals) of diurnal cycle (e.g., pre-dawn, mid-morning, mid-afternoon and post-sunset). Needed for representative sites at low, mid and high latitudes; low and high thermal inertia non-polar sites; one site dominated by local topography (e.g., canyon or edge of layered terrain). Vertical temperature profiling (1-3 levels minimum) highly desired through first few meters.

Technology development needed: some.

g) Returned samples to study the physical, chemical, and geological properties of rocks and soils and their interaction with the atmosphere and hydrosphere. Samples taken from 1 m depth soil and of rock weathering rinds; samples needed from one representative low-latitude site (0 to 30°), and one high latitude site (60-90°). *Technology development needed: much*.

2. Investigation: Determine the present-day stable isotopic and noble gas composition of the present-day bulk atmosphere. These provide quantitative constraints on the evolution of atmospheric composition and on the source and sinks of the major gas inventories.

Measurements

a) In situ, high-precision measurements of atmospheric isotopic composition at one site. +/- 5 per mil for 18-O/16-O, 17-O/16-O, 13-C/12-C; +/- 250 per mil for D/H, anywhere on the planet. *Technology development needed: much*.

b) Sample return of pristine atmospheric samples for measurement of key elements such as 40-Ar and 129-Xe. *Technology development needed: much*.

3. Investigation: Determine long-term trends in the present climate. This determination will test to what degree the Martian climate is changing today.

Measurements

a) Extension of the orbital and lander measurements of (A1) to multiple Mars years. *Technology development needed: much*.

b) Long-term (at least 10 years), in situ monitoring of key atmospheric variables (e.g., pressure, temperature, dust opacity, water) at globally representative sites (network science) for at least 12 sites. *Technology development needed: much*.

4. Investigation: Determine the rates of escape of key species from the Martian atmosphere, and their correlation with solar variability and lower atmosphere phenomenon (e.g. dust storms). Requires: Global orbiter observations of species (particularly H, O, CO, CO2 and key isotopes) in the upper atmosphere, and monitoring their variability over multiple Martian years.

Measurements

a) Map from orbit the 3-D distribution of key atmospheric neutral and charged species such as H, O CO CO2 and key isotopes. Technology development needed: none.

b) Measure from orbit the variations of key atmospheric neutral and charged species (H, O, CO, CO2, and key isotopes) over seasonal cycles, through dust storm events, and over the solar cycle. *Technology development needed: none*.

5. Investigation: **Search for micro-climates**. Detection of exceptionally or recently wet or warm locales and areas of significant change in surface accumulations of volatiles or dust would identify sites for in situ exploration. Requires global search for sites based on topography or changes in volatile distributions and surface properties (e.g., temperature or albedo).

Measurements

a) Detect hot spots (e.g., surface geothermal activity) at spatial resolution of <100 m. *Technology development needed: some*.

b) Detect local concentrations of water vapor, particularly within the lowest 1-3 km the atmosphere at spatial resolution <100 m. Regions repeatedly surveyed during spring and summer seasons. *Technology development needed: some*.

6. Investigation: **Determine the production and reaction rates of key photochemical species (O3, H2O2, CO OH etc.) and their interaction with surface materials.**

Measurements

a) Measure species in the atmosphere with sensitivities of 109 cm=3 as a function of insolation. *Technology development needed: some*.

b) Measure and identify surface complexes or chemabsorbed species on a representative sample (sample return or in situ ?) of surface materials (primary and secondary materials). *Technology development needed: much*.

B. Objective: Characterize Mars' ancient climate and climate processes (investigations in priority order)

1. Investigation: Find physical and chemical records of past climates. These provide the basis for understanding the extent and timing (e.g., gradual change or abrupt transition) of past climates on Mars. Requires: remote sensing of stratigraphy and aqueous weathering products, landed exploration, and returned samples.

Measurements

a) Remote sensing of 100s of target sites in the visible at 15 cm/pixel or better to characterize fine-scale layers in sedimentary deposits. The interpretation of high-resolution data requires lower-resolution context images. *Technology development needed: some*.

b) Hyperspectral orbital remote sensing at resolutions of 20-50 m/pixel to search for and characterize aqueous alteration and deposition products such as carbonates, hydrates, and evaporites. *Technology development needed: some*.

c) In situ exploration of layered deposits to characterize the physical structure of layers the chemistry, trace elements, isotopic (especially H, N, and O), mineralogy, and petrology for two regions (polar and non-polar) on the planet, at multiple stratigraphic locations at each site. *Technology development needed: much*.

d) Returned samples of soils, rocks, atmosphere, and trapped gasses/ices to measure the chemistry, mineralogy, and ages. A single sample is a major advance, but multiple samples spanning a range of ages is highly desirable. *Technology development needed: much*.

2. Investigation: **Characterize history of stratigraphic records of climate change at the polar layered deposits, the residual ice caps**. The polar regions suggest repeated geologically recent climate change. A key to understanding their histories is relative dating of polar layering and volatile reservoirs**. Requires orbital, in situ observations and returned samples**.

Measurements

a) Orbital or aerial platform remote sensing of 100s of sites in the visible at 15 cm/pixel or better to characterize fine-scale layers in both north and south polar layered deposits. *Technology development needed: some*.

b) Hyperspectral orbital remote sensing at resolutions of 20-50 m/pixel to search for and characterize physical properties, composition and morphology, volatile composition of north and south polar deposits. If NIR spectra are used, the coverage should extend to 4 microns. *Technology development needed: some*.

c) In situ, local exploration of layered deposits in north and south polar regions to characterize the physical structure of layers, volatile content, chemical and isotopic (especially H, N, and O) variations. measurements should be conducted at multiple stratigraphic locations at each site. *Technology development needed: much*.

d) Returned samples of polar layered deposits which preserve fine-scale stratigraphy, ices and trapped gasses, and enable measurements of chemistry, mineralogy, and determination of ages. Multiple samples spanning a range of ages are desirable to search for episodic volcanic activity, major impact events, or large-scale environmental variability due to changes in Mars' orbital and axial elements. *Technology development needed : much*.

III. GOAL: DETERMINE THE EVOLUTION OF THE SURFACE AND INTERIOR OF MARS ("Geology")

A. Objective: **Determine the nature and sequence of the various geologic processes (volcanism, impact, sedimentation, alteration etc.) that have created and modified the Martian crust and surface (investigations in priority order)**

1. Investigation: **Determine the present state, distribution and cycling of water on Mars**. Water is arguably the most important geologic material that influences most geological processes including the formation of sedimentary, igneous and metamorphic rocks, the weathering of geological materials, and deformation of the lithosphere. **Requires global observations using geophysical sounding and neutron spectroscopy, coupled with measurements from landers, rovers, and the subsurface**.

Measurements

a) Global search for water to a depth of several kilometers at spatial scales of ~ 100 m and to a depth resolution of 100 m. *Technology development needed: some*.

b) Aerial platform remote sensing to search for subsurface water to a depth of 500m at a depth resolution of 10 m and a spatial resolution of 100 m. *Technology development needed: some*.

c) Acquire vertical profiles of the distribution of subsurface liquid water and ice at several sites where water is likely from the sounding measurements in (a) and (b). *Technology development needed: much*.

d) In-situ drilling to liquid water or ice to depths up to a kilometer for at least one site and to depths of several hundred m for several sites with down-hole instruments to determine elemental abundances, mineralogy of volatile and other phases, including ices. *Technology development needed: much*.

e) Identify and measure the abundance of water-bearing minerals for several diverse sites of different ages. *Technology development needed: much*.

2. Investigation: **Evaluate sedimentary processes and their evolution through time, up to and including the present**. Fluvial and lacustrine sediments are likely sites to detect traces of prebiotic compounds and evidence of life. Sediments also record the history of water processes on Mars. Eolian sediments record a combination of globally-averaged and locally-derived fine-grained sediments and weathering products. Sediments are also likely past or present aquifers. **Requires knowledge of the age, sequence, lithology and composition of sedimentary rocks (including chemical deposits), as well as the rates, durations, environmental conditions, and mechanics of weathering, cementation, and transport processes.**

Measurements

a) Global stereo imaging with at least 10 m/pixel resolution and contiguous regional coverage of at least 1 percent of the planet at better than 1 m/pixel. *Technology development needed: none*.

b) Global orbital remote sensing with access to the entire planet at 30 m/pixel in the visible to reflected infrared (0.4 to 5 micrometers) with a spectral resolution of 10 cm-1. *Technology development needed: some*.

c) In-situ measurements, including traverses across sedimentary units of different ages. for several sites to determine physical properties of rocks and fines and their chemistry, mineralogy, lithology and petrology. Characterization should be sufficient to identify the rock types, their mode of deposition and degree of alteration. *Technology development needed: some*.

d) Returned samples for detailed characterization from at least several sites containing water-lain sediments, for which valid surface ages can be obtained in order to constrain the sedimentary record. *Technology development needed: much*.

e) Drilling to 1 km at one site and to ~100 m at several sites to determine the physical properties of rocks and fines and their chemistry, mineralogy, and petrology. *Technology development needed: much*.

3. Investigation: **Calibrate the cratering record and absolute ages for Mars**. The evolution of the surface, interior, and surface of Mars, as well as possible evolution of life, must be placed in an absolute timescale, which is presently lacking for Mars. Requires absolute ages on returned rock (not soil) samples of known crater ages.

Measurements

a) Returned samples of volcanic rocks whose cratering age dates the same event as its radiometeric age from at least two key sites, chosen to resolve uncertainties in crater ages (one focusing on early to mid Mars history and, one relatively young). *Technology development needed: much*.

b) Measurement of current impact flux from seismic network and an infrasonic network operating for 1 Mars year, using 12 stations arrayed in triangular groups of 3 spaced 100-200 km apart. *Technology development needed: much*.

c) Measurement of the current impact flux from by orbital detection of ionospheric perturbations induced by meteorite entry. *Technology development needed: much*.

4. Investigation: Evaluate igneous processes and their evolution through time, including the present. This study includes volcanic outgassing and volatile evolution. Volcanic processes are the primary mechanism for release of water and atmospheric gasses that support potential past and present life and human exploration. Sites of present day volcanism, if any, may be prime sites for the search for life. **Requires global imaging, geologic mapping, techniques for distinguishing igneous and sedimentary rocks, evaluation of current activity from seismic monitoring, and returned samples**.

Measurements

a) Orbital remote sensing, including stereo, in the visible (better than 1 m/pixel with ~10 m/pixel context images as listed above in A.2.a) and hyperspectral data of 30 m/pixel spatial resolution for key igneous regions of Mars (~20 % of surface). *Technology development needed: some*.

b) In situ measurements from the surface for at least several volcanic sites to determine chemistry, mineralogy, and petrology. Characterization should be sufficient to identify the rock types and will require a payload with significantly more capability than Athena. *Technology development needed: some*.

c) Global seismic monitoring of potential volcanic activity using an array of broad-band (0.05 to 50 Hz) seismometers (12 stations in groups of three with an internal spacing of 100-200 km) distributed globally. *Technology development needed: some*.

d) Returned samples of a variety of igneous rocks from at least two sites of different ages and types for geochemical, isotopic, mineralogical and petrographic analysis to understand the chemistry and physical process in the magma source regions and how they have changed with time. *Technology development needed: much*.

e) Search for thermal anomalies at a horizontal resolution of 10s of m. *Technology development needed: some*.

5. Investigation: Characterize surface-atmosphere interactions on Mars, including polar, eolian, chemical, weathering, and mass-wasting processes. Interest here is in process that have operated for the last million years as recorded in the upper 1 m to 1 km of geological materials. Understanding present geologic, hydrologic, and atmospheric processes is the key to understanding past environments and possible locations for near-surface water. Knowing the chemistry and mineralogy of both near surface rocks and alteration products is essential for calibrating remote sensing data. This study also has strong implications for resources and hazards for future human exploration. **Requires orbital remote sensing of surface and subsurface, and in situ measurements of sediments and atmospheric boundary layer processes.**

Measurements

a) Orbital remote sensing, including stereo, in the visible (better than 1 m/pixel with 10 m/pixel context), and hyperspectral (30 m/pixel) for key terrains (a total of ~ 20 % of the surface). *Technology development needed: none*.

b) Global SAR mapping of subsurface structures (below surficial materials) at depths up to several meters at spatial resolutions of 100 m/pixel. *Technology development needed: some*.

c) In-situ analysis of sediment grain size distribution, textures, composition and mineralogy of the regolith and characterization of the weathering rind on rocks at several sites . *Technology development needed: some*.

d) Network of at least 16 stations to monitor weather (temperature, pressure, wind velocity and strength) with concurrent visual observations from the surface and from orbit. Mission lifetime of three Mars years to determine seasonal and internal variations. *Technology development needed: none*.

e) A diverse set of returned samples, including soil profiles, duricrust and rock, from several sites (for detailed mineralogy of weathered products, isotopic fractionation, nature of weathering rinds, if any, and so on). *Technology development needed: much*.

6. Investigation: Determine the large-scale vertical structure and chemical and mineralogical composition of the crust and its regional variations. This includes, for example, the structure and origin of hemispheric dichotomy. The vertical and global variation of rock properties and composition record formative events in the planet's early history, place constraints on the distribution of subsurface aquifers, and aid interpretation of past igneous and sedimentary processes. **Requires remote sensing and geophysical sounding from orbiters and surface systems, geologic mapping, in-situ analysis of mineralogy and composition of surface material, returned samples, and seismic monitoring.**

Measurements

a) Global remote sensing, including stereo, in the visible (better than 1/m/pixel with 10 m/pixel context), and hyperspectral (30 m/pixel). *Technology development needed: none*.

b) SAR Mapping of subsurface structure to depths up to several m and at 100 m spatial resolution. *Technology development needed: some*.

c) In situ measurements of physical properties of rocks and fines for chemistry, mineralogy, petrology for at several sites of diverse ages and types *Technology development needed: none*.

d) Long-term (at least 1 Mars year) global seismic measurements using an array of broad-band (0.01 to 20 Hz) seismometers (at least 12 stations distributed in groups of at least 3, with internal spacing of 100-200 km). *Technology development needed: none*.

e) Returned samples of igneous rocks from several diverse units of different ages for detailed physical, chemical, and geologic analyses. *Technology development needed: much*.

f) Global gravity survey to precision of 10 mgal spatial (wavelength) resolution of 175 km. This will require precision tracking at low (~200 km) altitude and application of drag compensation techniques. *Technology development needed: some*.

g) Drilling to 1 km at one site and to ~100 m at several sites to determine the physical properties of rocks and fines and their chemistry, mineralogy, and petrology. *Technology development needed: much*.

h) Active seismic reflection and refraction measurements to delineate the third dimension, density and physical properties of the crust and geological units. *Technology development needed: some*.

i) Regional gravity surveys to precision of <1 mgal over spatial scales of tens of meters for understanding the local third dimensional geometry of the crust and geological units. *Technology development needed: some*.

7. Investigation: Document the tectonic history of the Martian crust, including present activity. Understanding of the temporal evolution of internal processes places constraints on release of volatiles from differentiation and volcanic activity and the effect of tectonic structures (faults and fractures in particular) on subsurface hydrology. **Requires geologic mapping using global topographic data combined with high-resolution images, magnetic and gravity data, and seismic monitoring.**

Measurements

a) Global remote sensing, including stereo, in the visible (better than 1/m/pixel with 10 m/pixel context), and hyperspectral (30 m/pixel). *Technology development needed: none*.

b) Global magnetic measurements (spacing better than 50 km) to an accuracy of better than 0.5 nT at an altitude no greater than 100-120 km. *Technology development needed: some*.

c) Regional magnetic surveys in regions with substantial anomalies using aerial platforms at altitudes of 1-5 km. *Technology development needed: much*.

d) Global gravity survey to precision of 10 mgal spatial (wavelength) resolution of 175 km. This will require precision tracking at low (~200 km) altitude and application of drag compensation techniques. *Technology development needed: some*.

e) Regional gravity surveys to precision of <1 mgal over spatial scales of tens of meters for understanding the geometry of structural features with depth. *Technology development needed: some*.

f) Active seismic reflection and refraction measurements to delineate the geometry (with depth) of structures and tectonic features and regions. *Technology development needed: some*.

g) Measure crustal in situ stress and strain in drill holes using well pressurization, bore hole break outs, and down hole, well logging measurement techniques. *Technology development needed: much*.

8. Investigation: Evaluate the distribution and intensity of impact and volcanic hydrothermal processes through time, up to and including the present. Hydrothermal systems are thought to be the connected with the earliest evolution of life on the Earth. Hydrothermal systems also play an important role in the chemical and isotopic evolution of the atmosphere, and the formation of the Martian soil. Deposits from hydrothermal systems have the potential to record the history of the biosphere and crust-atmosphere interactions throughout Martian history. **Requires knowledge of the age and duration of the hydrothermal system, the heat source, and the isotopic and trace element chemistry and mineralogy of the materials deposited.**

Measurements

a) Global and detailed imaging to search for and characterize candidate volcanic and impact crater locations, including volcanoes with channels systems, and impact crater walls and central uplifts. *Technology development needed: none*.

b) In-Situ measurements, including traverses across hydrothermal systems present at the surface or exposed by impacts, or other erosional processes with capabilities similar to those listed under A.2.c. *Technology development needed: some*.

c) Returned samples covering the range of available lithologies from at least several sites ranging from very recent to very old. *Technology development needed: much.*

B. Objective: Characterize the structure, compostion, dynamics, and history of Mars' interior (investigations in priority order)

1. Investigation: Characterize the configuration of Mars' interior. This is needed to understand the origin and thermal evolution of Mars and the relationships to surface evolution and release of water and atmospheric gasses. **Requires orbital and lander data**.

Measurements

a) Global gravity survey to 10 mgal precision and 175 km spatial resolution. *Technology development needed: some*.

b) Global magnetic measurements spaced <50 km to an accuracy of 0.5 nT or better at an altitude <100-120 km. *Technology development needed: some*.

c) Concurrent measurement of rotational dynamics from at least two landers to a precision better than 10 cm. *Technology development needed: none*.

d) Global seismic monitoring using an array of very broad-band (DC to 10 Hz) seismometers (at least 12 stations in groups of 3 with internal spacing of 100-200 km) operating for 1 Mars year. *Technology development needed: some*.

e) Returned samples of a variety of fresh volcanic rocks from several diverse sites, including those where rocks excavated from deep within the crust by large impacts are available for sampling. *Technology development needed: much*.

2. Investigation: Determine the history of the magnetic field. Evidence that Mars had a magnetic field early in its history has important implications for the retention of its early atmosphere and for the shielding of the surface from incoming radiation and the possible evolution of life. **Requires orbiter in eccentric orbit or low-altitude platform**.

Measurements

a) Global magnetic measurements (spacing < 50 km) to an accuracy of better than 0.5 nT from an altitude <100-120 km. *Technology development needed: some*.

b) Regional magnetic surveys in areas with a large remanent signature using aerial platforms at altitudes of 1-5 km. *Technology development needed: some*.

c) Samples of a variety of volcanic rocks of different ages from different sites, the sampling being performed such that knowledge of the orientation of the samples is preserved. *Technology development needed: much*.

d) Long-term (at least 1 Mars year) global seismic measurements using an array of broad-band (0.01 to 20 Hz) seismometers (at least 12 stations distributed in groups of at least 3, with internal spacing of 100-200 km). *Technology development needed: much*.

3. Investigation: Determine the chemical and thermal evolution of the planet. Knowledge of the thermal evolution places constraints on the composition, quantity, and rate of release of volatiles (water and atmospheric gasses) to the surface. **Requires** measurements **from orbiter and lander.**

Measurements

a) Global gravity survey to 10 mgal precision and 175 km spatial resolution. *Technology development needed: some*.

b) Global magnetic measurements spaced <50 km to an accuracy of 0.5 nT or better at an altitude <100-120 km. *Technology development needed: some*.

c) Concurrent measurement of rotational dynamics from at least two landers to a precision better than 10 cm *Technology development needed: none*.

d) Global seismic monitoring using an array of very broad-band (DC to 10 Hz) seismoneters (at least 12 stations in groups of 3 with internal spacing of 100-200 km) operating for 1 Mars year. *Technology development needed: some*.

e) In situ heat flow measurements to a precision of 5 mW/m2 for at least sites representing highland crust, lowlands, and recent volcanism. *Technology development needed: much*.

f) Returned samples of a diverse array of igneous rocks of different ages. *Technology development needed: much*.

GOAL IV: PREPARE FOR HUMAN EXPLORATION

Updated November 13, 2000 (does not include Nov 15-17 MEPAG results; no electronic input received)

A. Objective: Acquire Martian environmental data sets (priority order of investigations under review)

1. Investigation: **Determine the radiation environment at the Martian surface and the shielding properties of the Martian atmosphere.** The propagation of high energy particles through the Martian atmosphere must be understood, and the measurement of secondary particles must be made at the surface to determine the buffering (or amplifying) effects of the Martian atmosphere, and the backscatter effects of the regolith. Requires simultaneous monitoring of the radiation in Mars' orbit and at the surface, including the ability to determine the directionality of the neutrons at the surface.

Measurements

a) Measure charged particle spectra, at the surface and in orbit, accumulated absorbed dose and dose rate in tissue as a function of time over time, particulary at solar maximum and solar minimum. *Technology development needed: some*.

b) Determine the radiation quality factor, determine the energy deposition spectrum from 0.1 keV/um to 1500 keV/um, and separate the contributions of protons, neutrons, and HZE particles to these quantities. *Technology development needed: none*.

c) Measure neutron energy spectrum from 100 keV to 50 MeV or above. The ability to obtain information on the source of the neutrons (depth in soil, atmosphere) is a strongly desirable feature and therefore provisions for assessing direction of incidence of the neutrons is required. *Technology development needed: some*.

d) Simultaneous surface and orbital measurements are required to determine the shielding component of the atmosphere. *Technology development needed: some*.

e) Simultaneously measure the atmospheric pressure at the surface of Mars and the atmospheric dust loading. *Technology development needed: some*.

f) Measure the natural radioactivity of the planet's surface materials (soil and rocks). *Technology development needed: none*.

2. Investigation: Characterize the chemical and biological properties of the soil and dust. Toxicity and reactivity needed to develop hazard mitigation strategies to ensure safety of human explorers on the Martian surface. Requires in-situ experiments. If in-situ experiments can not achieve adequate levels of risk characterization, returned samples will be required. The requirements can and may have to be met through sample studies on Earth. Earth smaple return provides significant benefits to HEDS technology development programs.

Measurements

a) In situ determination of the toxic trace elements and mineral species including, but not limited to As, Be, Cd, Cl, F, and Pb. *Technology development needed: some*.

b) Determine the toxic and genotoxic potential of dust and soil to biological cell analogs (enzymes, lipids, nucleic acids, etc), to identify reactivity of quasi-cellular systems from which the potential for acute toxicity for human explorers could be inferred. *Technology development needed: some*.

c) Determine the chemical reactivities with a sensitivity of ppm (of particular interest are changes in the reactivities upon heating, with exposure to humidity, and with emphasis on the identification and volatility of the gases evolved) and, up to a maximum depth of 150 cm. Understand the solubility in water of martian soil (total weight loss after water is equilibrated with the soil), the before and after composition of the soil, and the composition of the aqueous phase in equilibrium with martian soil. *Technology development needed: much*.

d) Determine the depth of the superoxidation zone at several locations. *Technology development needed: much*.

e) In situ sensors or analytical tools to determine the content of carbon and complex organic compounds in wind-blown dust, surface soil, and materials from secluded environments to a sensitivity of 10 (?) PPM. *Technology development needed: much*.

f) Biohazard assessment. *Technology development needed: much*.

g) Determine physical properties (size, shape, hardness, adhesion) of representative dust samples: *Technology development needed: some*.

3. Investigation: Understand the distribution of accessible water in soils, regolith, and Martian groundwater systems. Water is a principal resource to humans. Requires geophysical investigations and subsurface drilling and in situ sample analysis.

Measurements

a) Map the Martian subsurface for ice and liquid water reservoirs. *Technology development needed: much*.

b) Measure the vertical distribution (and ultimately comprehensive 3-demensional subsurface maps) of permafrost, water ice and liquid water with a vertical resolution of ~ 10 m at selected sites. *Technology development needed: much*.

c) Determine the adsorbed and bound water content of soil samples from several provenances (air-borne dust, surface fines, sand dunes) with precision of +/- 10% down to levels of 0.1%. Determine the release temperature of water over the range 0oC-600oC. *Technology development needed: much*.

4. Investigation: Measure atmospheric parameters and variations that affect atmospheric flight. Pressure and density versus altitude, temporal and spatial variations. **Requires instrumented aeroentry shells or aerostats.**

Measurements

a) Measure and record pressure versus altitude, and temperature for all Mars entry vehicles during the E/D/L phase of the mission. *Technology development needed: some*.

b) Measure basic surface meteorology: temperature, pressure, wind speed and direction at different sites. *Technology development needed: some*.

c) Monitor global weather patterns from orbit. *Technology development needed: none*.

d) Measure the frequency and magnitude of dust storms selected surface locations; characterize the processes active in these storms in terms of the associated wind speeds, pressure changes, atmospheric dust loading. *Technology development needed: none*.

e) Detect local atmospheric vorticity in terms of frequency of local "dust devil" development, quantity of dust lofted, associated wind speeds and pressure differentials. *Technology development needed: none*.

5. Investigation: Determine electrical effects in the atmosphere. Needed to understand the role of electrical discharge, electrostatic effects, etc. in atmospheric processes, including dust-raising and potential hazards to surface operations. **Requires experiments on a lander.**

Measurements

a) Measure the electrical properties of dust in the atmosphere and observe the consequences of dust electrification. *Technology development needed: much*.

b) Determine the atmospheric electrification due to turbulent motion in dust clouds and dust storms; determine the population of atmospheric ions and whether there is a diurnal variation; determine what types of discharges occur on Mars. *Technology development needed: much*.

c) Determine the electrostatic charge state (magnitude, sign, and longevity of charges) for both aerosols and soil particles up to 100 microns. *Technology development needed: much*.

d) Determine Paschen curves (electrical breakdown in gases) for Mars as a function of temperature, pressure, wind, dust load in atmosphere, and season for meteorological use and as a tool for designing and safeguarding equipment for Mars exploration. *Technology development needed: some*.

6. Investigation: Measure the engineering properties of the Martian surface. Soil and surface engineering data (bearing strength, angle of repose, geoelectric properties, etc.) **Requires in-situ measurements at selected sites.**

Measurements

a) Measure soil bearing strength and surface penetration resistance. *Technology development needed: none*.

b) Measure soil cohesion and angle of repose. *Technology development needed: none*.

c) Measure soil magnetic and electrostatic properties (adhesion potential, strength of adhesion and character of the charge). *Technology development needed: some*.

d) Measure surface temperature and touch temperature of surface features. *Technology development needed: none*.

e) Measure surface heat capacity. *Technology development needed: none*.

f) Measure surface albedo. *Technology development needed: none*.

g) Measure surface thermal conductivity/insulation properties. *Technology development needed: some*.

h) Determine the particle size and distribution, in the range 0.01 to 10.0 microns (0.01 to about 10 cm surface depth), with higher emphasis on particles much smaller than 1.0 micron. *Technology development needed: some*.

i) Determine the total columnar suspended load of dust in the atmosphere. *Technology development needed: some*.

j) Measure average surface sink temperature. *Technology development needed: some*.

k) Determine soil and dust chemical composition. *Technology development needed: some*.

l) Measure the conductivity, resistivity, dielectric constant, and piezoelectric properties of the subsurface to a depth of 10 m as a function of latitude, time of year, and geological environment. *Technology development needed: some*.

m) Measure subsurface distribution of ground ice. *Technology development needed: some*.

7. Investigation: Determine the radiation shielding properties of Martian regolith. Soil and dust from the Martian surface offer a readily available source of shielding material for surface crews. The thickness of the required regolith cover will depend upon the measured shielding properties. **Requires an understanding of the regolith composition, a lander with the ability to bury sensors at various depths up to a few meters. Some of the in situ measured properties may be verified with a returned sample**.

Measurements

Determine the radiation shielding characteristics of Martian regolith as a function of cover depth. Radiation sensors would be placed under various depth of regolith cover, and their readings correlated with an unburied sensor. *Technology development needed: much*.

8. Investigation: Measure the ability of Martian soil to support plant life. Determine the ability of the indigenous soil to support life, such as plant growth, for future human missions. R**equires in-situ measurements and process verification.**

Measurements

Conduct in situ process verification of plant growth experiment through full plant growth, seed and re-germination cycle. *Technology development needed: much*.

9. Investigation: **Characterize the topography, engineering properties, and other environmental characteristics of candidate outpost sites**. Site certification for human outposts requires a set of data about the specific site that can best be performed by surface investigations. **Specific measurements are listed in other investigations.**

10. Investigation: Determine the fate of typical effluents from human activities (gases, biological materials) in the Martian surface environment.

Measurements

a) Determine the rate of reaction of typical materials exposed to the Martian environment. *Technology development needed: much*.

b) Monitor the rate of dispersion of analog materials in the Martian environment. *Technology development needed: much*.

B. Objective: Conduct in-situ engineering science demonstrations (priority order of investigations under review)

1. Investigation: Demonstrate terminal phase hazard avoidance and precision landing. Necessary to decrease the risks associated with soft landing, and to enable pinpoint landing. Requires flight demonstration during terminal descent phase.

Measurements

a) Demonstrate terrain recognition systems (e.g. LIDAR)

b) Utilize hazard avoidance algorithms during terminal descent.

c) Demonstrate controlled terminal descent and soft landing.

2. Investigation: Demonstrate mid-L/D aeroentry /aerocapture vehicle flight. Mid-L/D (0.4-0.8) aeroentry shapes will be required as payload masses increase. Mid-L/D aeroassist increases landed vehicle performance and landing precision. Requires wind tunnel testing and flight demonstration during aeroentry phase of the mission.

Measurements

a) Flight test slender body, mid L/D (.4-0.8) aeroentry shapes.

b) Achieve and verify an actual horizontal position error at parachute deployment of ±10 km or less. This value includes an Entry Aero-Maneuvering Control error goal of ±2 km error, the Mars approach phase navigation error, map tie errors, parachute deployment variables, etc.

c) Use approach navigation which provides control of the flight path angle at the defined entry interface to ±0.5 deg or less and pre-entry knowledge of ±0.1 deg or less.

d) Provide control to remain well within the expected control authority of the Entry Aero-Maneuvering system and the knowledge is needed to provide initiation of the Entry Aero-Maneuvering system IMU.

e) The ability to obtain this approach navigation performance with radio navigation depends on selection of a low-latitude landing site location (latitude between 30 deg N and 30 deg S. High latitude sites would require optical approach navigation.

f) Reconstruct the entry trajectory (after the fact) to an accuracy of ±1 km or better to provide verification of the Entry Aero-Maneuvering system performance.

g) Demonstrate aerocapture maneuver in the Martian atmosphere at speeds within the envelope for Human Missions (5.7-8.7 Km/sec in reference mission)

h) Collect vehicle attitude, trajectory, guidance and control system performance data, and free stream conditions for entire aeropass (atmospheric entry through heat shield ejection);

i) Collect heatshield performance for use in CO2 chemistry model validation, predictions of aerothermal loads and TPS system response;

j) Collect temperatures at selected points within and on heat shield;

k) Collect pressure at selected points on the body;

l) Validation of flight trajectory determination vs. prediction including aerodynamic predictions and atmospheric modeling; and

m) Analysis of the performance of the Guidance & Control system, including sensors, attitude control system and CPU.

3. Investigation: Demonstrate high-Mach parachute deployment and performance. Higher ballistic coefficient entry vehicles will be result from flying more massive landers. This will result in higher parachute deploy speeds, which are beyond the qualification of current parachute systems. **Requires high-altitude Earth-based testing and flight demonstration during Mars entry phase.**

Measurements

a) Demonstrate and qualify parachute deploy in an expanded velocity regime (up to M=3.0 [TBD])

b) emonstrate parachute deploy characteristics in the flow field trailing a mid-L/D aeroentry vehicle

4. Investigation: Demonstrate in-situ propellant (methane, oxygen) production (ISPP) and in-situ consumables production (ISCP) (fuel cell reagents, oxygen, water, buffer gasses). Components which directly interact with the Martian environment should be evaluated in a relevant environment to determine their performance. End-to-end performance may be evaluated by acquisition of local resources, processing, storage and use of end products. **Requires process verification with in-situ experiments.**

Measurements

a) Demonstrate the intake and adsorption of carbon dioxide from the Martian atmosphere;

b) Demonstrate thermal management concepts of heat transfer between the components of the ISPP plant as well as to the outside environment;

c) Monitor the performance degradation characteristics of advanced solar array and radiator concepts operated in the actual Mars environment;

d) Evaluate the functionality of electrostatically removing accumulated dust off the solar array; and

e) Understand the characteristics of zirconia cells to generate propellant-grade oxygen.

f) Demonstrate "end-to-end" system-level operation of ISPP and ISCP processes, including acquisition of resources, chemical processing, storage of products, and demonstration level use of the products.

g) Demonstrate in-situ consumables production (ISCP), such as buffer gas (nitrogen and argon) or water extraction.

5. Investigation: Access and extract water from the atmosphere, soils, regolith, and Martian groundwater systems. Water is a principal resource. Requires in-situ operations to determine hydrologic characteristics of aquifers and aquicludes. Requires subsurface drilling.

Measurements

a) Demonstrate autonomous drilling operations on the Martian surface.

b) Demonstrate progressively deeper drilling, beginning with pilot drill demonstrations to 10's of meters, and concluding with depths corresponding to subsurface aquifers.

c) Demonstrate extraction of water from subsurface aquifers.

d) Demonstrate the extraction of water from Martian permafrost layers.

e) Demonstrate the ability to extract potentially useful quantities of water from the atmosphere

f) Demonstrate the extraction of water from Martian regolith (hydrated minerals.)

6. Investigation: Demonstrate deep drilling. The Martian subsurface will provide access to potential resources (e.g., water) as well as providing access to valuable scientific samples. **Requires landed demonstration**.

Measurements

a) Demonstrate autonomous drilling operations on the Martian surface.

b) Demonstrate progressively deeper drilling, beginning with pilot drill demonstrations to 10's of meters, and concluding with depths corresponding to subsurface aquifers.

C. Objective: Emplace infrastructure for (future) missions (priority order of investigations under review)

1. High capacity power systems to support ISPP activities in support of robotic sample return missions and eventual human support.

Performance Targets

a) 300 watts per kilogram solar power generation

b) Megawatt-class surface nuclear power

c) Megawatt-class space solar power arrays

2. Communication infrastructure to support robotic missions with high data rates or a need for more continuous communications, and eventual human support.

Performance Targets

a) 1 Mb/sec bandwidth at maximum Earth-Mars distance.

b) 99% (TBD) communications link availability, other than during superior conjunction.

3. Navigation infrastructure to support precision landings for robotic or human missions.

Performance Targets

a) Provide navigation infrastructure which will allow arriving Mars spacecraft multi-point tracking and nav state determination.

b) Provide navigation infrastructure which will allow determination of surface spacecraft location to (TBD) meters.

Appendix 1

Participants in the MEPAG/Mars Peer Review Group meeting, 22-24 February 2000

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Appendix 2

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Morrison, A.	JPL
Naderi, F.	JPL
Nealson, K.	JPL
*Niehoff, J.	SAIC
Orosei, R.	CNR/Italy
Paige, D.	UCLA
Palluconi, F.	JPL
Papanastassiou, D.	JPL
Pate-Cornell, E.	Stanford
Peach, L.	NASA HQ
Phillips, M.	JPL
Pilcher, C.	NASA HQ
Riegler, G.	NASA HQ
*Rogers, B.	Self
Saunders, S.	JPL

Appendix 2 (continued)

Schmidt, R.	ESA/ESTEC
Senske, D.	JPL
*Sotin, C.	Univ. Nantes/France
*Sullivan, T.	JSC/NASA
*Taylor, J.	Univ. Hawaii
Thompson, T.	JPL
Viotti, M.	JPL
*Waenke, H.	MPIC Mainz/Germany
Weitz, C.	NASA/HQ
Zurek, R.	JPL

*MEPAG member

Appendix 3

Participants at the MEPAG meeting, 15-17 November 2000

Agee, C.	JSC
Allen, C.	JSC
*Arvidson, R.	Wash. Univ.
Beaty, D.	JPL
*Bianchi, R.	CNR IAS
*Bibring, J.P.	IAS
Blaney, D.	JPL
*Briggs, G.	ARC/NASA
Campbell, J.	JPL
*Carr, M.	USGS
*Christensen, P.	Ariz. State Univ.
Coradini, M.	ESA HQ
*Counil, J.L.	CNEC
Clifford, S.	LPI
Cutts, J.	JPL
Dawson, S.	JPL
Dolgin, B.	JPL
*Duke, M.	LPI
*Farmer, J.	Ariz. State Univ.
Gershman, B.	JPL
*Golombek, M.	JPL
*Greeley, R.	Ariz. State Univ.
Hoffmann, H.	DLR
Hubbard, S.	NASA HQ
Jordan, F.	JPL
*Kendall, D.	CSA
Kohlhase, C.	JPL
Lavery, D.	NASA HQ
Lindstrom, D.	JSC
*MacPherson, G.	Smithsonian
Martin, G.	NASA HQ
Matousek, S.	JPL
McCleese, D.	JPL
*McKay, D.	JSC
Miller, S.	JPL
Morrison, A.	JPL
Mugnuolo, R.	ASI
Naderi, F.	JPL
*Niehoff, J.	SAIC
Olivieri, A.	ASI
*Paige, D.	UCLA
Palluconi, F.	JPL

Appendix 3 (continued)

Papanastassiou, D.	JPL
Parrish, J.	NASA HQ
Pate-Cornell, E.	Stanford
Peach, L.	HEDS/USRA
Piccioni, G.	CNR-IAS
Plaut, J.	JPL
Pline, A.	NASA HQ
*Raulin, F.	LISA
Reiter, D.	Stanford
Rummel, J.	NASA HQ
Saunders, S.	JPL
Senske, D.	NASA HQ
Soffen, G.	GSFC
Stabekis, P.	Lockheed Martin
Thompson, T.	JPL
*Van Dover, C.	William & Mary College
Vane, G.	JPL
Viotti, M.	JPL
*Waenke, H.	MPIC Mainz/Germany
Yen, A.	JPL
*Zent, A.	NASA ARC
Zimmerman, J.	Intl. Sp. Svcs.
Zurek, R.	JPL

*MEPAG member

Appendix 4

Members of the Mars Ad hoc Science Team (MAST)

McCleese, D. (Chair)	JPL
Arvidson, R.	Wash. Univ.
Carr, M.	USGS
Drake, M.	Univ. Ariz.
Farmer, J.	Ariz. State Univ.
Garvin, J.	NASA/HQ
Greeley, R.	Ariz State Univ.
McSween, H.	Univ. Tenn.
Soderblom, L.	USGS

Exhibit VI – Scout Concept Abstract Submittal Format

Layout Instructions: Maximum Ten (7), 8 1/2" X 11" pages not including cover sheet and cost page(s), smallest font is Times New Roman 10 pt, except for tables and charts, where smallest font is Times New Roman 8 pt. One inch left and right margins and One inch top and bottom margins.

Science Goals and Objectives

- Goals and objectives of the investigations; their value to the Mars Program; and their relationship to past, current, and future investigations and missions.
- The measurements to be taken in the course of the mission, the data to be returned, and the approach that will be taken to achieve the scientific objectives of the investigation.
- The relationship between the data products generated and the scientific objectives should be explicitly described, as should be the expected results.

Science Implementation

- Instrumentation
  - Mass, power, volume, data rate(s), pointing, and pointing accuracy, as well as resolution, precision/sensitivity, heritage, and calibration requirements.
  - Science-to-Mission Traceability Matrix Flow-down from science objective, to instrument performance to observational plateform selection should be clearly supported.
- Mission
  - Observing profile (orbit, surface location(s), observing periods, etc.)
- Data Analysis and Archiving Strategy
- Science Team
  - The capabilities, roles, affiliations, and experience of all members of the proposed science team must be described.

Mission and Flight System Architecture

Within this section, describe the development that will assure mission success. Include the following items to the degree they are known:

- General
  Launch date, launch energy, launch vehicle, mission duration, trajectory type, final orbit, landing site, etc.
- Communications (Uplink/Downlink)
  Date rates and volume (kbps, Mbytes/day), onboard storage (Mbytes), number of data dumps per day, and maximum data latency if relevant to mission operations or science objectives. Number of uplinks per day and number of Bytes per uplink.
- Resources and Margins (Provide estimates for mass, power, and reserves at the system level).
- Attitude and Control Requirements
  - Control method, control reference, attitude control and knowledge requirements as the relate to the science objectives.
  - Deployments, articulation, and in-flight calibration.
- Instrument Characteristics (for each instrument)

- Instrument mass, power, volume, and viewing direction. Data and power demand as a function of operation mode.
- Flight System Elements and Characteristics
  - Mass, Power, Power Source, Memory, Telecom, ACS, CDS, Propulsion Architecture - for all flight system elements

New Technology, Infrastructure and Risk Assessment

- New Technology (See Exhibit VIII for a Mars Technology Program Overview)
  1. Relationship between new technology and achieving science objectives.
  2. Identify enabling technologies and sources, and validation requirements.
  3. Technology development schedule, key infusion dates, and fall backs.
- Infrastructure (See Exhibit IV for link to NASA TMOD services)
  a. Use of telecom/nav Mars orbiting assets.
  b. Use of ground data and mission operations system.
  c. Deep Space Network tracking requirements.
- Risk Assessment
  - Approach to redundancy.
  - Integration and test.

Study Plan and Work Breakdown Structure

- Study Partner(s) including lead contact.
- Study Schedule.
- Work Breakdown Structure.
- Identification of study team members.
- Relationship of the study team to the study teamWork Breakdown Structure (WBS).
- The degree to which the experience and skills of the team members and the experience of the organization(s) are appropriate to the study tasks and assure a comprehensive and technically competent study effort.
- Time available for each person involved in the study.
- Past performance of the proposed organization in similar studies.
- Plan for identifying new technologies.
- Plan for quantifying ROM total mission cost, ROM per WBS, and ROM cost per fiscal year.
- Plan for specifying schedule, major risk items and risk reduction strategy.
- Management approach, including lines of responsibility and communication within and between organizations and with company management.

SCIENCE-TO-MISSION TRACEABILITY MATRIX

Science Driver	Instrument Requirement	Mission Requirement	Flight System Requirement	Comm and Ground Data System Requirement	Mission Operations Requirement	Technology Requirement
1.						
2.						
3.						
....						
n.						

Kinds of information to be addressed in the Matrix (not all inclusive):

<u>Requirements on Mission</u>
Orbit information (type, altitude, inclination)
Launch vehicle and any upper stages
Launch date and launch date flexibility
Mission duration
Number of Flight System Elements

<u>Requirements on Flight System</u>
Control method (3-axis stabilized, spinner, gravity-gradient)
Pointing control, knowledge, and jitter
Slew Rates
Data storage
Special thermal requirements
Power required by instruments
Radiation environment

<u>Requirements on Communications and Ground Data System</u>
Data Volume (Mbytes per day)
Number of data dumps per day
Real time requirements

<u>Requirements on Mission Operations</u>
Maneuvering, including constraints on timing, criticality, and duration.
Concept existing or not?

<u>Technology Requirements</u>
Enabling technology requirements including current capability versus desired capability, date new technology required

Exhibit VII - Oral Workshop Presentation Format

To facilitate a fair evaluation of ALL mission concepts, strict presentation guidelines will be adhered too. Presentations are limited to 20 min, 7-10 viewgraphs on a dual overhead projector system. The review board will ask questions for up to 10 minutes at the end of the 20 min. Also, for clarification purposes, the selection panel may call a presenter back at the end of the day for a brief closed-door question and answer period. Concept presentations must contain the following information and recommended format or may be deemed non-responsive to this call for concepts. Only data submitted in the written Concept Abstract may be presented.

- Name of mission, PI, Co-I's, and Partner's names, affiliations, and role (1 viewgraph).
- Science Goals and Objectives. (1 viewgraph).
- Science Implementation and flow-down from science investigation goals to measurement objectives to flight system selection to instrument performance (1 viewgraph). It is recommended that this information be presented in table format. An example of this table shown here.

SCIENCE-TO-MISSION TRACEABILITY MATRIX

Science Driver	**Instrument Requirement**	**Mission Requirement**	**Flight System Requirement**	**Comm and Ground Data System Requirement**	**Mission Operations Requirement**	**Technology Requirement**
1.						
2.						
3.						
....						
n.						

Kinds of information to be addressed in the Matrix (not all inclusive):

Requirements on Mission
Orbit information (type, altitude, inclination)
Launch vehicle and any upper stages
Launch date and launch date flexibility
Mission duration
Number of Flight System Elements

Requirements on Spacecraft Flight System
Control method (3-axis stabilized, spinner, gravity-gradient)
Pointing control, knowledge, and jitter

Slew Rates
Data storage
Special thermal requirements
Power required by instruments
Radiation environment

<u>Requirements on Communications and Ground Data System</u>
Data Volume (Mbytes per day)
Number of data dumps per day
Real time requirements

<u>Requirements on Mission Operations</u>
Maneuvering, including constraints on
Concept existing or not?

<u>Other Requirements</u>

Any other driving requirement on a mission element

- Mission and flight system architecture (1 to 2 viewgraph). Include picture/line drawing, mission timeline, key flight system elements, block diagram, etc.
- New technology identification and development plan (1 to 2 viewgraph)
- Education and public outreach (1 viewgraph).
- Concept Study plan, including identification of industry and/or other study partners (1 to 2 viewgraph).

Exhibit VIII - Mars Technology Program

Exhibit VIII
Mars Technology Program

Mars Technology Program Structure

Focused Technology

1.0	**ENTRY DESCENT AND LANDING**
1.1	Optical Nav
1.2	Guided Entry
1.3	Subsonic Parachute
1.4	Descent Propulsion
1.5	Hazard Detection & Avoidance
1.6	Touchdown Systems
1.7	EDL Mission Simulation
2.0	**SURFACE POWER**
2.1	RPS Power Generation
2.2	Solar Power Generation
2.3	Power Storage
3.0	**SAMPLE RETURN TECHNOLOGIES**
3.1	Forward Planetary Protection
3.2	Ascent Vehicle Technology
3.3	Space Rendezvous and Sample Capture
3.4	Sample Containment & Earth Return
3.5	Returned Sample Handling (MRSH Technology)

Base Technology

4.0	**REGIONAL MOBILITY AND SUBSURFACE ACCESS**
4.1	Rovers
4.2	Aerial Platforms
4.3	Subsurface Exploration
4.4	Science Operations & Visualization
5.0	**SCIENCE INSTRUMENTS AND SYSTEMS**
5.1	Mars Instrument Development Porgram (NRA)
5.2	In-situ Life Detection
6.0	**TELECOM & NAVIGATION**
6.1	Deep Space Communications
6.2	Mars Proximity Communications
6.3	Radio Based Navigation
6.4	Communication Protocols and Coding
7.0	**TRANSPORTATION/ORBIT INSERTION**
7.1	Aerocapture
7.2	Space Propulsion
8.0	**ADVANCED EDL**
8.1	Advanced EDL Technologies
9.0	**INFORMATION SYSTEMS**
9.1	MDS

3/2/01

2

Focused Technologies

Mars Focused Technologies
EDL Technology

WBS ELEMENT	DESCRIPTION - GOALS AND APPROACH
Optical navigation	Design, build and test small optical navigation camera capable of providing entry corridor accuracy of better than 0.5km. Validate ability to use Phobos as the reference target for both precision landing and aerocapture missions.
Guided Entry	Develop guided entry vehicle capable of maintaining a ballistic course from entry to parachute deployment given uncertainties in atmospheric profile, winds and aerodynamic performance
Subsonic Parachute	Demonstrate a low q low Mach number parachute with potential for EDL enhancements including paraguidance
Descent propulsion	Demonstrate descent engine systems including thrusters, throttle valve, and high flow presssure requlators for carrying out a controlled descent to the Mars surface. Recapture and improve Viking thruster technology.
Hazard Detection and Avoidance	Detect hazards such as rocks and slope that represent a hazard to the lander using an active sensor such as LIDAR or radar and develop a strategy for avoiding these hazards and directing the lander to the nearest accessible safe site
LIDAR	Demonstrate a brassboard LIDAR sensor capable of generating elevation maps of the surface of Mars from a lander descending towards the surface that can be used to detecting hazards such as rocks and steep slopes.
Robust Landing	Demonstrate a robust landing system capable of attenuating the impact of a nominal propulsive landing with hazard avoidance and tolerant to off nominal performance of both hazard detection and avoidance systems and descent systems.
EDL Mission Simulation	Conduct high fidelity end-to-end simulations of Generation 2 EDL systems to validate mission concepts. Evaluate performance and risk. Support project life cycle needs ranging from off-line mission simulation to real time mission simulation.

3/2/01 4

Surface Power

WBS ELEMENT	DESCRIPTION - GOALS AND APPROACH
Radioisotopic Power	Provide sustained presence and survivability for long duration missions on the surface of Mars through the use of radioisotopic power conversion technology. Conserve Plutonium through the use of high efficiency energy converters
Solar Power	Improve solar collection efficiency on the Mars surface by developing improved means of dust removal.
Power Storage	Improve the performance of batteries at low temperatures. Develop batteries with lower survival temperatures (need to discuss with Rao Surumpudi and update.

3/2/01

5

Mars Sample Return Technologies

WBS ELEMENT	DESCRIPTION - GOALS AND APPROACH
Forward Planetary Protection	Protect Mars from contamination from Earth-sourced organisms and preventing the introduction of Earth-sourced organisms into the returned sample. Validate the effectiveness of these techniques using precision analysis and modeling techniques.
Mars Ascent Vehicle	Inject a canister containing the sample into Mars orbit, deep space or an Earth return trajectory to accomplish the most efficient and cost effective transfer of the sample to Earth. Validate the performance and reliability of the vehicle.
Sample Tracking Rendezvous & Capture	Track, rendezvous and capture a canister containing the Mars sample in Mars orbit, deep space or in Earth orbit. Valdiate the performance and reliability of the recovery method.
Sample Containment and Earth Return	Provide containment of the returned sample, breaking the chain of contact with the Mars surface to the extent needed to meet planetary protection requirements. Validate usign Probabilistic Risk Assessment methods using ground and flight test data.
Returned Sample Handling	Retrieve the sample after landing or from Earth orbit. Contain and protect the sample during hazard assessment. Develop techniques of hazard assessment and investigation of the science value of the returned sample.

3/2/01 6

Regional Mobility and Subsurface Access

WBS ELEMENT	DESCRIPTION - GOALS AND APPROACH
Rovers	Ability to transport payload extended distance over Mars surface terrains, to provide a platform for in-situ science and a capability for sample acquisition and possibly ascent vehicle deployment
Aerial Vehicles	Ability to deploy payloads on extended flights in the Mars atmosphere primarily for the purpose of making observations of the Mars surface from a close vantage point.
Subsurface Access	Access to a range of depths in the Martian surface using drilling systems or robotic moles. These devices will bring samples to the surface or make in-situ analyses
Science Operations and Visualization	Develop software tools to assist operations of landed assets on the surface of Mars.

3/2/01

7

Base Technologies

Science Instruments and Systems

WBS ELEMENT	DESCRIPTION - GOALS AND APPROACH
Mars Instrument Development Program	Development of Ground Demonstrated Miniature Instruments (TRL 3,4) into Space Qualifiable Hardware (TRL 5,6) Ready for Response to Mars Flight AO.
In-Situ Life Detection	Obtain evidence for past and present life on the subsurface and beneath the surface of Mars using in situ measurements Devise new techniques for life detection that make minimal assumptions about the nature of life on Mars.

Communication/Radio Navigation Technologies

WBS ELEMENT	DESCRIPTION - GOALS AND APPROACH
Deep Space Communications	Increase data return capability on ìtrunk lineî deep space link between Mars and Earth Increase lander direct-to-Earth data rate capabilities from 1 kbps (MER) to 10 kbps
Proximity Link Communications	Provide proximity link relay communications capabilities to enable increased data return and increased connectivity with future Mars assets
Radio-Based Navigation	Develop radio-based precision approach navigation capable of sub-km entry state knowledge
Protocols and Coding	Define Mars Network communications protocol architecture capable of evolvable, interoperable connectivity

3/2/01

10

Transportation/Orbit Insertion

WBS ELEMENT	DESCRIPTION - GOALS AND APPROACH
Aercapture	Use aerodynamic lift and drag to enter Mars orbit from an approach trajectory with propulsion only used for control functions and periapsis raising
Space Propulsion	Develop lightweight chemical and electrical propulsion systems with smaller system mass and higher specific impulse.

Information Systems

WBS ELEMENT	DESCRIPTION - GOALS AND APPROACH
Missions Data Systems	Establish a unified approach to flight, ground, and test systems for EDL and landed assets.

EXHIBIT IX

SPECIMEN CONTRACT

STATEMENT OF WORK

The statement of work will be added shortly